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Astrometric Telescope Facility: Preliminary Systems Definition Study

Volume II: Technical Description

May 1987

National Aeronautics and
Space Administration

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NASA Technical Memorandum 89429

ASTRONOMIC TELESCOPE FACILITY: PRELIMINARY SYSTEMS DEFINITION STUDY VOLUME II: TECHNICAL DESCRIPTION

Edited by Charlie Sobeck
May 1987

Cover, Title Page, and Spine: The cover, title page, and spine of NASA TM 89429 has the wrong title on the paper. The word astronomic should be astrometric. Attached are stickers to put over the cover page's title, the title page's title, and the spine's title.

The new title should read:

ASTROMETRIC TELESCOPE FACILITY:
PRELIMINARY SYSTEMS DEFINITION STUDY
VOLUME II: TECHNICAL DESCRIPTION

MJF:july 1987

NASA Technical Memorandum 89429

Astrometric Telescope Facility: Preliminary Systems Definition Study

Volume II: Technical Description

Edited by Charlie Sobeck, Ames Research Center, Moffett Field, California

May 1987

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

PREFACE

This report documents the results of the Astrometric Telescope Facility (ATF) Preliminary System Definition Study conducted in the period between March and September 1986. The main body of the report consists primarily of the charts presented at the study final review which was held at NASA Ames Research Center on July 30 and 31, 1986. The charts have been revised to reflect the results of that review. Explanations for the charts are provided on the adjoining pages where required. Note that charts which have been changed or added since the review are dated 10/1/86, unchanged charts carry the review date 7/30/86. In addition, the report contains a narrative summary of the study results and two appendices. The first appendix is a copy of the ATF Characteristics and Requirements Document generated as part of the study. The second appendix shows the inputs to the Space Station Mission Requirements Data Base (MRDB) submitted in May 1986.

The report is being issued in three volumes. Volume I contains an executive summary of the ATF mission, strawman design, and study results. Volume II contains the detailed study information. Volume III contains the detailed ATF cost estimate, and will have limited distribution.

The study and report presented here are the result of a team effort including personnel from the University of Arizona, the Allegheny Observatory, the University of California at San Diego, and the Ames Research Center. Members of the team were:

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ATF PRELIMINARY SYSTEM DEFINITION STUDY

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ATF ABBREVIATIONS AND ACRONYMS

AEDC	Arnold Engineering Development Center
AGS	Advanced Gimbal System
ARC	Ames Research Center
ARCMIN	Arcminute
ARCSEC	Arcsecond
ASE	Airborne Support Equipment
ASPS	Annular Suspension and Pointing System
ASSY	Assembly
ATF	Astrometric Telescope Facility
AU	Astronomical Unit
AVG	Average
ber	Bit Error Rate
BR	Network Bridge
C	Celsius
CCD	Charge Coupled Device
CDS	Command and Data Subsystem
CG	Center of Gravity
C/L	Center Line
cm	Centimeter, Center of Mass
COMPLEX	Comittee on Planetary and Lunar Exploration
CONTD	Continued
CPS	Coarse Pointing System
CRT	Cathode Ray Tube
CSSA	Committee on Space Sciences and Astronomy
CTE	Coefficient of Thermal Expansion
D	Diameter
dB	Decibel
DC	Direct Current
DEC	Declination
DEF	Definition
DIA	Diameter
DMS	Data Management System

DOD	Department of Defense
EDP	Embedded Data Processor
EFL	Effective Focal Length
EMC	Electromagnetic Compatibility
EVA	Extravehicular Activity
FOV	Field of View
FPI	Focal Plane Instrument
ft	Feet
FWD	Forward
g	Gram, Gravity
Gbit	Gigabit
gm	Gram
GR/EP	Graphite-Epoxy
GSFC	Goddard Space Flight Center
HST	Hubble Space Telescope
H/W	Hardware
Hz	Hertz
IN.	Inch
INST	Instrument
IOC	Initial Operating Capability
IPS	Inertial Pointing System
IR	Infrared
I/F	Interface
J	Joules
JSC	Johnson Space Center
K	Kelvin
kbps	Kilobits per Second
kg	Kilogram
km	Kilometer
KSC	Kennedy Space Center
kW	Kilowatt
lbf	Pound-Force
lbs	Pounds
LEO	Low Earth Orbit
LOS	Line of Sight
LPL	Lunar and Planetary Laboratory

m	Meter
MAP	Multichannel Astrometric Photometer
mm	Millimeter
MB	Megabyte
Mbps	Megabits per Second
MDM	Multiplexer/Demultiplexer
MGMT	Management
MHz	Megahertz
MIN	Minute
MIPS	Mega-Instructions per Second
MPAC	Multipurpose Applications Console
MRDB	Mission Requirements Data Base
MSC	Mobile Servicing Center
MSFC	Marshall Space Flight Center
MSU	Mass Storage Unit
MUX/DEMUX	Multiplexer/Demultiplexer
N	Newtons
NAR	Nonadvocate Review
NIU	Network Interface Unit
ORU	On-orbit Replaceable Unit
PIU	Power Interface Unit
PMT	Photomultiplier Tube
PSD	Power Spectral Density
QSO	Quasi-Stellar Object
RA	Right Ascension
RAD	Radius
RFP	Request For Proposal
RMS	Root Mean Square
SAA	South Atlantic Anomaly
SAVI	Space Active Vibration Isolation
SCU	Signal Conditioning Unit
SDP	Standard Data Processor
SEC	Second
SETI	Search for Extraterrestrial Intelligence
SIRTF	Space Infrared Telescope Facility
SME	Solar Mesospheric Explorer

SOT	Solar Optical Telescope
SS	Space Station
SSEC	Solar System Exploration Committee
STS	Space Transportation System
S/W	Software
TBD	To Be Determined
TDRS	Tracking and Data Relay Satellite
TGS	Time and Frequency Generation System
UOA	University of Arizona
V	Volts
VDC	Volts-direct current
W	Watts
X-STRAP	Cross-strap
Å	Angstrom
(°)	Degree
⊕	Earth
μsec	Microsecond
μ	Micron

1.0 INTRODUCTION

1.1 Rationale for Astrometric Telescope Facility

The Astrometric Telescope Facility (ATF) is to be an Earth-orbiting facility designed specifically to measure the change in relative positions of stars. The position of the star of interest, referred to as the "target star", is determined relative to other stars in the telescope field of view, referred to as "reference stars". The primary science investigation for the facility will be the search for planets and planetary systems outside our solar system. In addition the facility will support astrophysics investigations dealing with the location or motions of stars. The science objectives and facility capabilities for astrophysics investigations are discussed in section 2.0.

The facility is designed to detect Neptune/Uranus-size planets about stars at distances up to 10 parsecs. To meet this requirement the facility must be capable of measuring relative motions to an accuracy of the order of 10 μarcsec. Current theories predict that planetary systems are a natural consequence of star formation; therefore, the mission requires investigation of the order of 100 target stars to obtain adequate statistics such that a negative result (i.e., no planetary systems discovered) would be significant, forcing reconsideration of our present understanding of how the Solar System was formed.

Present capability of ground-based systems is the order of 1 marcsec with the expectation that accuracies of about 400 μarcsec can ultimately be achieved. It has been estimated that the accuracy of the Hubble Space Telescope (HST) will be the order of 2 marcsec. Since, for a given distance, the mass of the minimum size detectable planet is directly proportional to the measurement accuracy, the ATF will provide an improvement of 40 times relative to ground-based systems and 200 times relative to the HST.

INTRODUCTION
ASTROMETRIC TELESCOPE FACILITY — RATIONALE

- A SPACE-BASED FACILITY DESIGNED TO PRECISELY MEASURE STAR MOTIONS (RELATIVE TO REFERENCE STARS)

- PRIMARY MISSION OBJECTIVE
  - DETECTION AND STUDY OF EXTRASOLAR PLANETARY SYSTEMS

- ADDITIONAL MISSION CAPABILITIES
  - ASTROPHYSICS INVESTIGATIONS (MOTION OF NEARBY GALAXIES, ACCURATE STAR DISTANCE MEASUREMENTS, ETC.)

- SPECIFIC CAPABILITIES
  - POSITIONAL VARIATIONS TO ACCURACY OF 0.01 mARCSEC (TWO ORDERS OF MAGNITUDE OVER EARTH-BASED MEASUREMENTS)
  - DETECTION OF NEPTUNE/URANUS SIZE PLANETS TO DISTANCES ON THE ORDER OF10 PARSECS (33 LIGHT YEARS)
  - EXAMINATION OF ABOUT 100 STARS PLANNED

- CAPABILITIES OF ATF VERSUS OTHER SYSTEMS, HST

1.2 Measurement Approach

The ATF employs a single paraboloid mirror telescope design with a F/D ratio of about 13. The Focal Plane Instrument (FPI) has the capability of measuring the relative location of up to 32 stars. A Ronchi ruling (e.g., a glass plate with alternate transparent and opaque lines) moving across the focal plane of the telescope modulates the light from the stars. The relative location of the star images can then be determined by counting the integral number of lines between images and the relative phase of the modulated signals.

INTRODUCTION
MEASUREMENT APPROACH

- OPTICAL TELESCOPE WITH LONG FOCAL LENGTH (F/D=13)
  - RELATIVELY SIMPLE OPTICS
  - TARGET STAR AND UP TO 31 REFERENCE STARS IMAGED

- RONCHI RULING MOVING IN FOCAL PLANE MODULATES LIGHT FROM ALL STARS
  - SEPARATE CHANNEL DIGITAL RECORD OF LIGHT INTENSITY FOR EACH STAR
  - PHASE DIFFERENTIALS BETWEEN TARGET AND REFERENCE STARS PROVIDE SENSITIVE MEASURE OF RELATIVE POSITIONS
  - OVER PROJECT LIFE (20 YR) PROVIDES MOTION OF OBJECTS

1.3 Rationale for Space Station Utilization

The ATF has been designed as a Space Station (SS) payload. The SS is expected to provide a number of support services which will significantly reduce the complexity and cost of the ATF. Initial design, development and test costs are reduced by use of the SS services such as power and communications with the ground, SS hardware (H/W) including the Coarse Pointing System (CPS) and unit electronics designs, SS software (S/W), and the reduced system complexity resulting from the capability to replace failed units relatively easily. The SS use also reduces operational costs by eliminating the costs associated with communications links between the ATF and the ground.

INTRODUCTION
RATIONALE FOR SPACE STATION UTILIZATION

- LONG-LIFE, STABLE PLATFORM FOR ATF MISSION (20 YR)
- SERVICE AND REPAIR AVAILABLE AT MINIMUM COST
- COST REDUCED WITH AVAILABILITY OF COMMON SERVICES AND HARDWARE
  - SERVICES: POWER, COMMUNICATIONS, DATA STORAGE, POINTING MOUNT
  - QUALIFIED HARDWARE DESIGNS: MUX/DEMUX, COMPUTER, NETWORK INTERFACE UNIT

1.4-1 Historical Background

In the period between 1974 and the present, a number of science workshops have been held to discuss various approaches to search for extrasolar planetary systems. These workshops have concluded that planetary search programs should be supported and have recommended several approaches including both ground- and space-based systems. Among the various space-based systems, the ATF approach appears to be most promising. The workshops also identified a number of other types of astrophysical investigations which could be conducted by a facility with the ATF capabilities.

1.4-2 Historical Background (Contd)

Two system studies to define the feasibility of programs to search for extrasolar planets have been conducted. These studies concluded that such searches would be scientifically useful and are technically feasible. With regard to space-based systems the ATF approach appears to be the most straightforward and promising based on the present technology.

INTRODUCTION
HISTORICAL BACKGROUND

- SCIENCE WORKSHOPS
  - 1974 TO 1976: SIX SETI MEETINGS DEFINED EARLY STEPS TO STUDY EXTRASOLAR PLANETS
  - 1976: TWO WORKSHOPS LOOKED AT GROUND AND SPACE-BASED DETECTION TECHNIQUES
  - 1978 & 1979: WORKSHOPS FOCUSED ON GROUND-BASED TECHNIQUES
    - IDENTIFIED MOST PROMISING PROSPECTS: SPECKLE AND AMPLITUDE INTERFEROMETRY, LONG-FOCUS ASTROMETRY, AND HIGH RESOLUTION SPECTROSCOPY
    - RECOMMENDED START OF GROUND-BASED PROGRAMS: RADIAL VELOCITY AND SPECKLE TECHNIQUES
  - 1983: IDENTIFIED BASIC CRITERIA OF SCIENCE REQUIREMENTS FOR PLANET DETECTION
  - 1985: EXAMINED APPROACHES TO HIGH ACCURACY ASTROMETRIC TELESCOPE AND ASTROPHYSICS SCIENCE POTENTIAL

INTRODUCTION
HISTORICAL BACKGROUND (CONTD)

- SYSTEM STUDIES
  - 1976: PROJECT ORION
    - SYSTEM DESIGN ANALYSIS OF GROUND-BASED INSTRUMENT AND SPACE-BASED DIRECT DETECTION OF REFLECTED VISIBLE AND INTRINSIC IR RADIATION
    - CONCLUSION: SEARCH FOR EXTRASOLAR PLANETS SCIENTIFICALLY USEFUL AND TECHNICALLY FEASIBLE
  - 1982: COMPARATIVE STUDY OF ASTROMETRY USING PRIME FOCUS REFLECTOR VS INTERFEROMETRIC APPROACH PLANETARY DETECTION
    - STUDY DONE BY LOCKHEED
    - CONCLUSIONS: REFLECTOR APPROACH FEASIBLE, INTERFEROMETER TOO COMPLEX

1.4-3 Historical Background (Contd)

The ATF approach has been reviewed by a number of science peer group panels and in each case it has been agreed that it is a scientifically feasible and desirable approach.

Lockheed completed an advanced project study for NASA Ames Research Center (ARC) in March 1984. A Memorandum of Agreement with the University of Arizona was signed in January 1985, forming a joint University of Arizona/ARC team to advance the Astrometric Telescope Facility project. The ATF Preliminary System Definition Study described in this report was initiated in March of 1986.

INTRODUCTION
HISTORICAL BACKGROUND (CONTD)

- PEER REVIEWS BY CSSA, SSEC, AND COMPLEX
  - ALL CONCURRED THAT PLANETARY DETECTION IS SCIENTIFICALLY POSSIBLE AND DESIRABLE
- 1984: ARC STARTED ADVANCED STUDY OF SS-BASED ATF
- 1985: MEMORANDUM OF AGREEMENT BETWEEN UNIVERSITY OF ARIZONA AND AMES SIGNED
- 1986: PRESENT ATF PRELIMINARY SYSTEM DEFINITION STUDY

1.5 Programmatics

1.5.1 Organizational Responsibilities. - This page intentionally left blank.

INTRODUCTION
ORGANIZATIONAL RESPONSIBILITIES

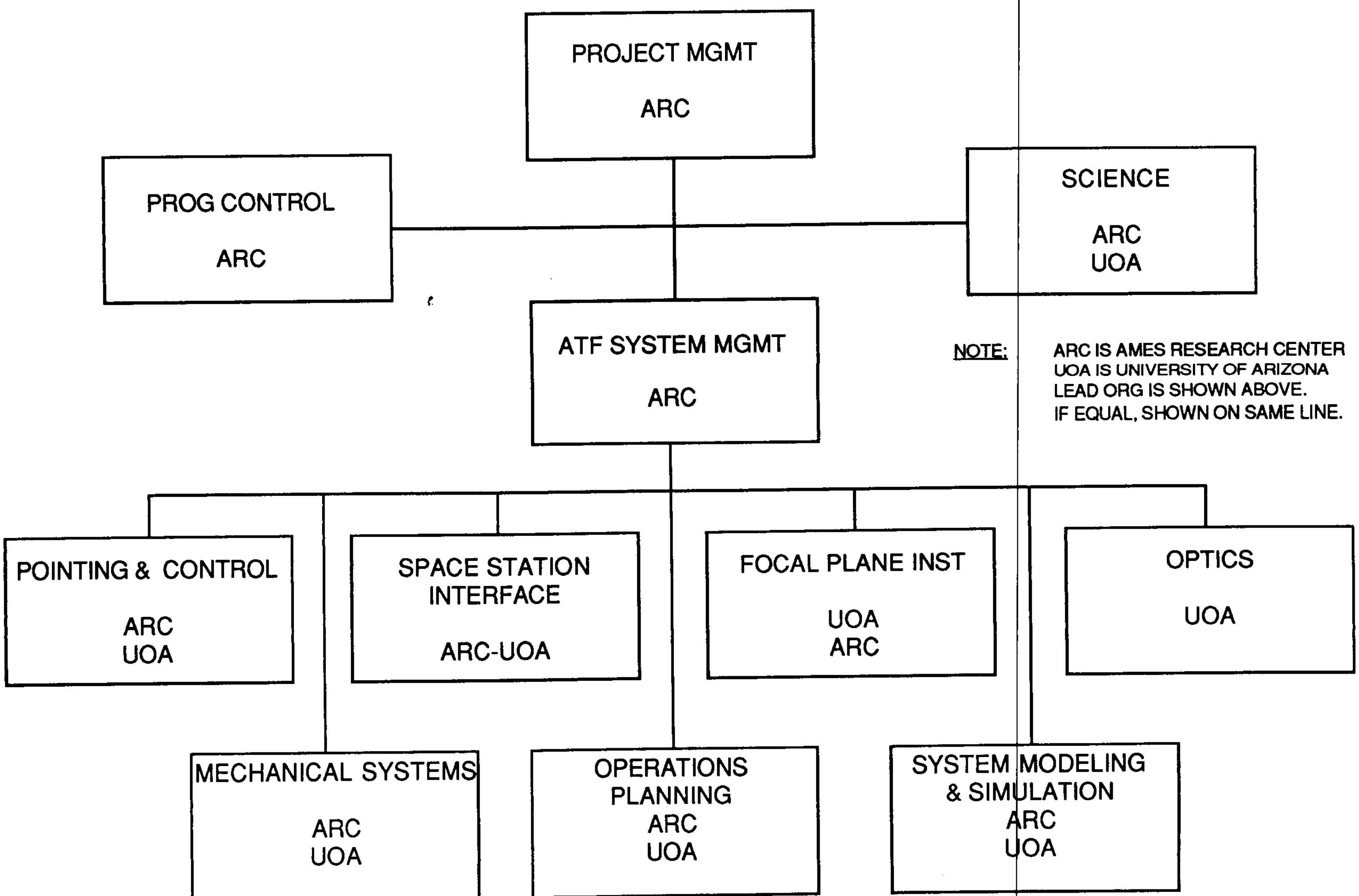
- MEMORANDUM OF AGREEMENT BETWEEN UNIVERSITY OF ARIZONA AND ARC — JANUARY 1985
  - RECOGNIZES JOINT INTEREST IN PROJECT AND ASSOCIATED SCIENCE
  - RECOGNIZES COMPLEMENTARY MANAGEMENT AND TECHNICAL CAPABILITIES
  - ESTABLISHES OVERALL APPROACH AND RESPONSIBILITIES

- DEVELOPMENT PHASE RESPONSIBILITIES SHOWN ON NEXT CHART

1.5.2 ATF Project Organization. - This page intentionally left blank.

ATF SYSTEMS STUDY

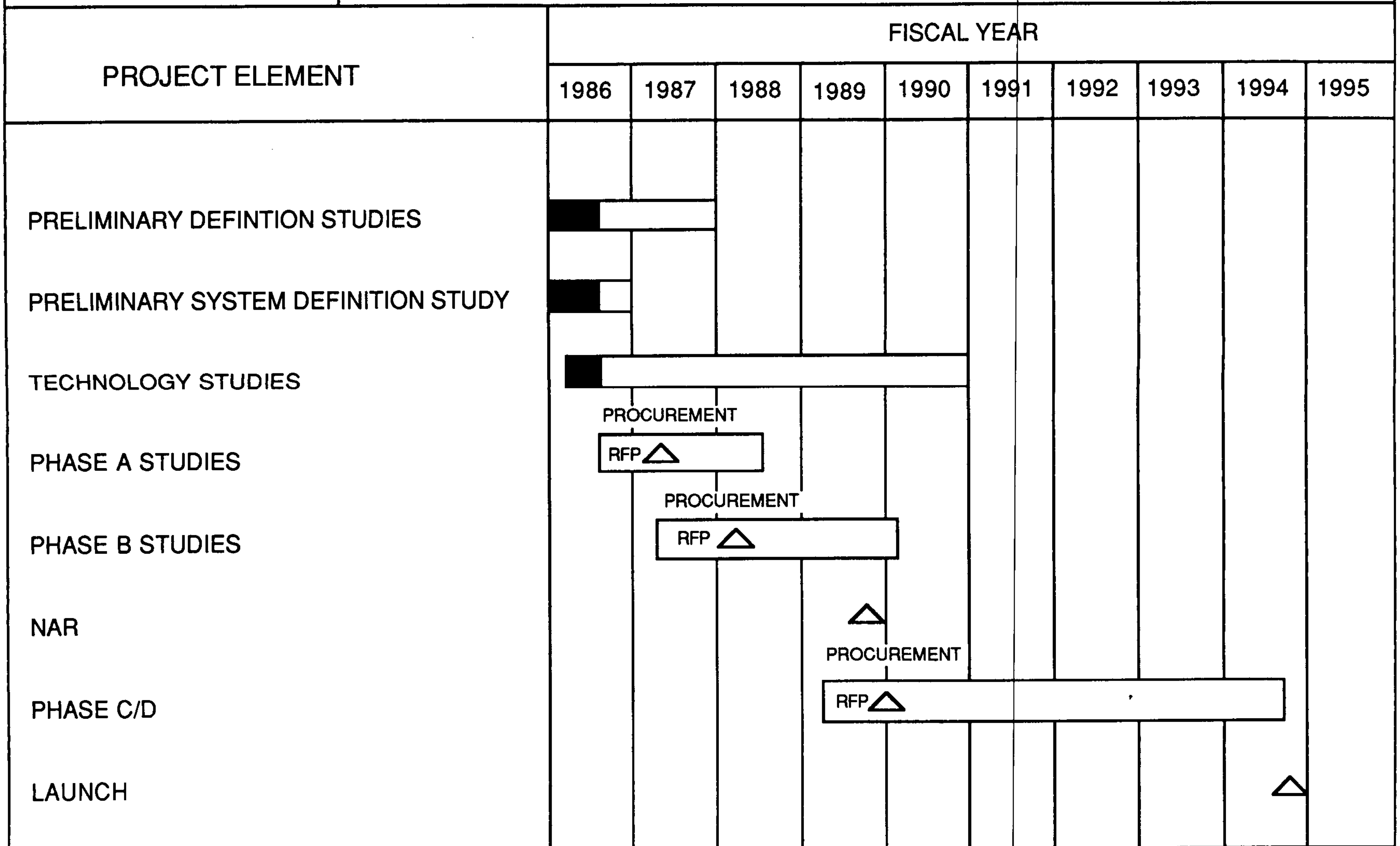
INTRODUCTION
ATF PROJECT ORGANIZATION



NOTE: ARC IS AMES RESEARCH CENTER
UOA IS UNIVERSITY OF ARIZONA
LEAD ORG IS SHOWN ABOVE.
IF EQUAL, SHOWN ON SAME LINE.

1.5.3 Project Schedule. - The schedule shown here is based on the assumption that the SS Initial Operating Capability (IOC) is in 1994 and that ATF is an IOC payload. Based on the 1994 date, the schedule is tight and meeting the milestones shown is essential. It is worth noting that the Non-Advocate Review must be held prior to the beginning of the budget development process in the Fall. Therefore, a slip of that milestone results in a full-year slip in the program.

INTRODUCTION
PROJECT SCHEDULE



NOTE: NAR = NON-ADVOCATE REVIEW RFP = REQUEST FOR PROPOSAL

1.6 Preliminary Systems Definition Study

1.6.1 Purpose. - The purposes of this study are shown on the accompanying chart. It is important to emphasize that the concept defined by the study is only a strawman against which the feasibility of accomplishing the mission requirements can be measured and a first-order cost estimate can be made. In addition, the study identifies areas where further work is required prior to, or as part of, the Phase A study.

INTRODUCTION
PRELIMINARY SYSTEM DEFINITION STUDY PURPOSE

- DEFINE MISSION AND SYSTEM REQUIREMENTS AND CHARACTERISTICS TO MEET SCIENCE OBJECTIVES
- DEFINE STRAWMAN CONCEPT FOR FACILITY AT PREPHASE A LEVEL WHICH MEETS SYSTEM REQUIREMENTS
- IDENTIFY SPECIFIC AREAS WHERE TRADE STUDIES OR TECHNOLOGY DEVELOPMENT ARE NEEDED
- ESTIMATE PROGRAM COST FOR STRAWMAN CONCEPT

1.6.2-1 Study Guidelines. - The study was based on the assumption that ATF will be an IOC payload on the SS and that one of the station CPSs will be provided for ATF use. The ATF system has been designed based only on IOC capabilities. A primary goal has been to use existing flight-qualified H/W wherever possible. Unit designs to be built and qualified for the station are included in this category. The study assumed a protoflight approach as defined in section 1.6.2-2.

INTRODUCTION
STUDY GUIDELINES

- THE ATF TO BE SS IOC PAYLOAD
- SPACE STATION WILL PROVIDE A CPS DEDICATED TO ATF USE
- ATF WILL USE SS UTILITIES
- ONLY IOC SS CONFIGURATION CONSIDERED, NO EFFORT DEDICATED TO USE OF IMPROVEMENTS OF STATION CAPABILITIES
- DESIGN TO USE EXISTING SPACE QUALIFIED HARDWARE TO MAXIMUM EXTENT POSSIBLE (INCLUDING HARDWARE TO BE BUILT AND QUALIFIED FOR STATION)

1.6.2-2 Study Guidelines (Contd). - This page intentionally left blank.

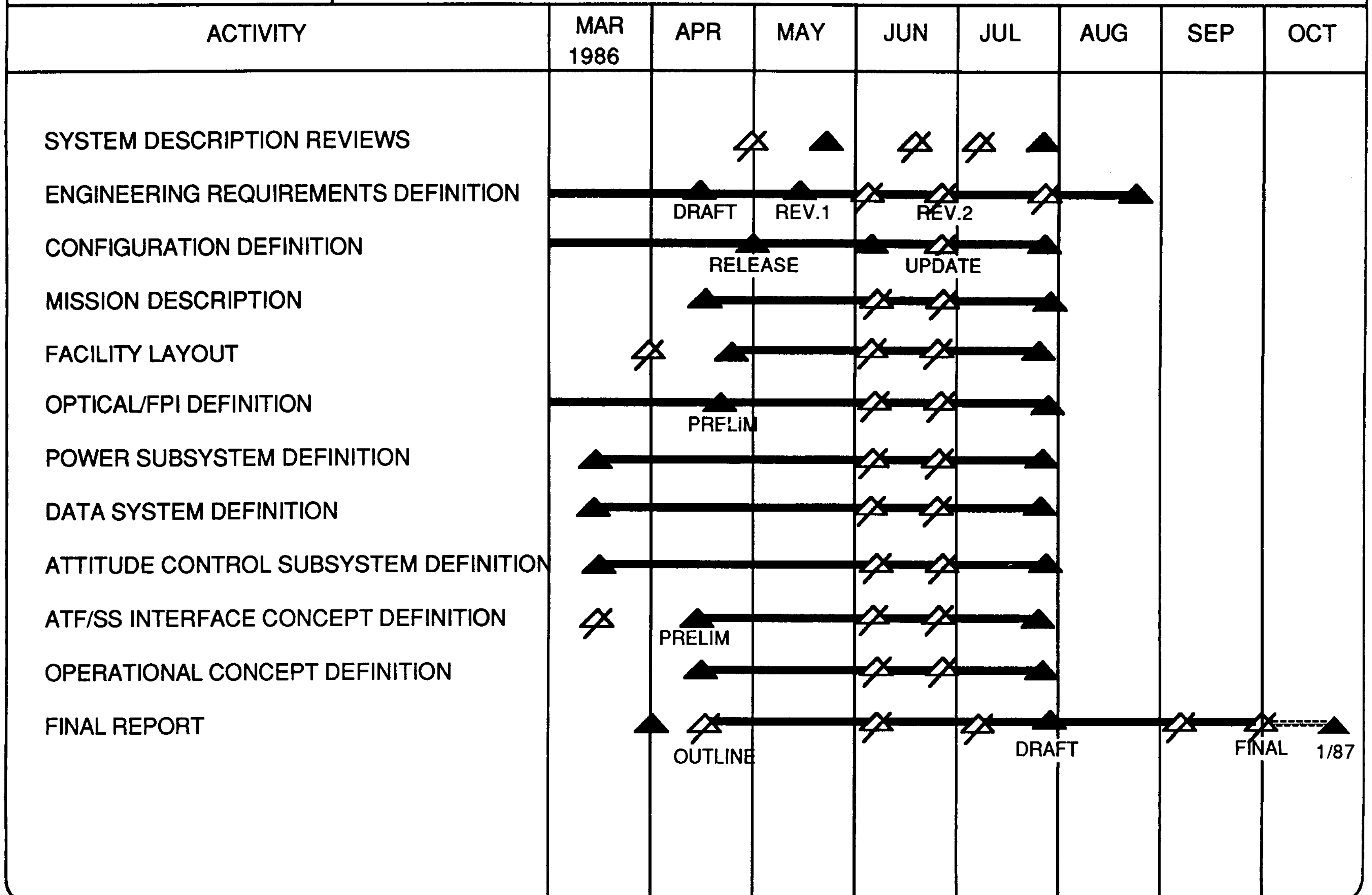
INTRODUCTION
STUDY GUIDELINES (CONTD)

- PROTOFLIGHT HARDWARE PROGRAM
  - ONE FLIGHT SYSTEM BUILT AND TESTED TO PROTOFLIGHT LEVELS
  - ONE FLIGHT SPARE FOR EACH ELECTRONIC UNIT
  - ONE FLIGHT SPARE FOCAL PLANE INSTRUMENT
  - THE STRUCTURE QUALIFIED USING ENGINEERING MODEL(S) TO QUALIFICATION LEVELS
  - QUALIFICATION UNIT BUILT AND TESTED TO QUALIFICATION LEVELS, FOR NEW ELECTRONICS BOXES, THEN MAINTAINED AS FLIGHT SPARE

1.6.3 Study Schedule. - The Preliminary System Definition Study was initiated in March 1986 and is concluded with this report. As indicated by the accompanying schedule chart, all milestones have been accomplished. The time to conduct the study exceeded the original estimate by about 6 wk.

ATF SYSTEMS STUDY

INTRODUCTION
SYSTEM DEFINITION STUDY



2.0 SCIENCE OBJECTIVES

2.1 Planetary Detection: Scientific Rationale

The Copernican Revolution began with the discovery that the Earth revolves about the Sun and is not the center of the Universe. Further steps in the revolution have shown us that the Sun is an ordinary star located relatively far from the center of our Milky Way Galaxy, and furthermore that the Milky Way is not an extraordinary galaxy among galaxies.

The Copernican Principle, then, is the notion that the Earth is ordinary in every way that we have been able to test. A major missing element of this picture is the answer to the question: are planets and planetary systems common?

Curiosity about this question and the need to test our (primarily theoretical) understanding of the process by which stars and planetary systems form are the main motives behind the search for other planetary systems.

SCIENCE OBJECTIVES
PLANETARY DETECTION: SCIENTIFIC RATIONALE

THE FUNDAMENTAL REASONS FOR SEEKING OTHER PLANETS ARE TO:

- SATISFY CURIOSITY ABOUT POSSIBLE COSMIC NEIGHBORS
- TEST THE COPERNICAN PRINCIPLE: IS THE EARTH IN A SPECIAL POSITION IN THE UNIVERSE, OR IS IT TYPICAL?
- VERIFY AND IMPROVE OUR UNDERSTANDING OF THE FORMATION OF PLANETARY SYSTEMS
- PROVIDE STATISTICAL DATA FOR RESEARCH IN PLANETARY FORMATION

2.1.1 Planetary Detection: Scientific Objectives. - A variety of questions about possible other planetary systems can be posed, many related to our attempt to understand the star and planet formation process. Of particular importance are questions that provide evidence on whether the basic theoretically derived understanding of the process of star and planet formation is correct.

SCIENCE OBJECTIVES
PLANETARY DETECTION: SCIENTIFIC OBJECTIVES

THE GOAL OF THE PLANET SEARCH PROGRAM IS TO INCREASE OUR UNDERSTANDING OF PLANETARY SYSTEMS BY STUDYING:

- THE FREQUENCY OF OCCURRENCE OF PLANETARY SYSTEMS
- THE DISTRIBUTION OF PLANETS AMONG STAR TYPES
- THE VARIETY OF PLANETARY SYSTEMS
- WHETHER PLANETARY SYSTEMS HAVE THE CHARACTERISTICS SUGGESTED BY THEORETICAL MODELS
- THE PLANETARY FORMATION PROCESS
- THE REMOVAL OF ANGULAR MOMENTUM FROM STELLAR SYSTEMS
- WHETHER PLANETS CAN FORM IN BINARY STAR SYSTEMS

2.1.2 Planetary Detection: Science Requirements. - The positive identification of other planetary systems would have profound implications, both philosophically and scientifically. In planning a search for other planets, it is highly desirable that a negative result (no or very few detections) also have important implications. The ATF project has been designed so that a null result would greatly alter our understanding of the star formation process.

SCIENCE OBJECTIVES
PLANETARY DETECTION: SCIENCE REQUIREMENTS

- SYSTEMATIC SURVEY OF A SAMPLE OF STARS OF VARIOUS KINDS
- SENSITIVE ENOUGH TO:
  - DETECT PLANETS AS SMALL AS URANUS OR NEPTUNE
  - SURVEY A STATISTICALLY SIGNIFICANT SAMPLE ($\approx$ 100 STARS)
  - ENSURE A NEGATIVE RESULT WOULD BE SIGNIFICANT
- ABLE TO FIND SYSTEMS VERY DIFFERENT FROM OURS
- PROVIDE USEFUL AUXILIARY INFORMATION ABOUT DETECTED PLANETS
- TECHNIQUE MUST BE RESISTANT TO BEING FOOLED (E.G., BY OTHER NATURAL PHENOMENA OR BY STATISTICAL FLUCTUATIONS)

2.2 Space Astrometry Applications

Planetary detection is not the only scientific project that could be accomplished with the ATF. Many exciting studies become possible with a space-based astrometric telescope.

SCIENCE OBJECTIVES
SPACE ASTROMETRY APPLICATIONS

THE ASTROMETRIC TELESCOPE FACILITY CAN CONDUCT A VARIETY OF ASTRONOMICAL RESEARCH:

- A SYSTEMATIC SEARCH FOR PLANETARY SYSTEMS
- DIRECT MEASUREMENT OF DISTANCES TO ANY STAR IN THE MILKY WAY GALAXY
  - DETERMINATION OF ACCURATE STELLAR LUMINOSITIES
  - DIRECT CALIBRATION OF COSMIC DISTANCE INDICATORS
- GREATLY IMPROVE KNOWLEDGE OF MOTIONS OF STARS AT ANY LOCATION IN THE MILKY WAY GALAXY
- PROVIDE SOME CAPABILITY FOR STUDY OF STELLAR MOTIONS IN NEARBY GALAXIES
- STUDIES OF MOTIONS OF STARS IN CLUSTERS
- QSO'S: LOWER LIMIT ON DISTANCES AND INFORMATION ABOUT VARIABILITY

2.3 Planetary Detection: Astrometric Requirements

Certain technical requirements are placed on an astrometric search program in order that the study be significant regardless of whether the results are positive or negative. The ones listed here assure that a sample of significant size is searched with enough sensitivity that Uranus/Neptune-class planets would be detected.

SCIENCE OBJECTIVES
PLANETARY DETECTION: ASTROMETRIC REQUIREMENTS

TO MEET THE GOALS, THE REQUIREMENTS FOR AN ASTROMETRIC SEARCH ARE:

- MUST SURVEY APPROXIMATELY 100 STARS WITHIN ABOUT 10 PARSECS OF THE EARTH
- MEASURE CHANGES IN RELATIVE POSITION TO ACCURACY OF 10 MICROARCSECONDS
- EACH STAR MUST HAVE ITS POSITION DETERMINED TO THIS ACCURACY UP TO 50 TIMES DURING A 20-YR MISSION
- POSITIONS MEASURED IN TWO PERPENDICULAR COORDINATES
- SYSTEMATIC ERRORS MUST BE LESS THAN RANDOM ERRORS
- MEASUREMENT SYSTEM AND REFERENCE FRAME MUST BE STABLE (FOR 10-20 YEARS)

3.0 ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS

3.1 Measurement Approach

3.1.1 Conventional Astrometry — Direct Imaging. - The conventional approach to astrometry is to image the star field on a photographic plate or detector array and determine star locations from the centroids of the images. The accuracy of this approach can be improved by taking numerous images of the star field, making precise measurements of the positions of the images and averaging together many such measurements. The accuracy achievable with such averaging processes is ultimately limited by the dimensional stability of the recording medium, as well as by its photometric uniformity, finite resolution, and, on the ground, by the Earth's atmosphere.

As shown on this chart, the requirements established for the ATF planetary detection investigation result in system requirements for resolution, dimensional stability, and photometric stability significantly beyond the present state of the art. Therefore, based on the present state of technology, the direct imaging approach is not feasible for ATF.

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
CONVENTIONAL ASTROMETRY — DIRECT IMAGING

- APPROACH
  - IMAGE STAR FIELD ON PHOTOGRAPHIC PLATE OR MULTI-ELEMENT ARRAY
  - DETERMINE STAR LOCATIONS FROM CENTROID OF IMAGES
- REQUIREMENTS
  - HIGH RESOLUTION: 10,000 X 10,000 PIXELS, 50-mm SQUARE
  - VERY HIGH DIMENSIONAL STABILITY: CHANGE IN RELATIVE POSITION ORDER OF 10^{-6} mm
  - HIGH PHOTOMETRIC UNIFORMITY: RELATIVE CHANGE IN SENSITIVITY ACROSS PIXEL ON THE ORDER OF 1 PART IN 10^4
- IMPLEMENTATION: REQUIREMENTS SIGNIFICANTLY BEYOND PRESENT STATE OF THE ART

3.1.2-1 Ronchi Ruling Concept. - An alternative to the conventional approach to astrometry is to use a Ronchi ruling (a grating with alternating opaque and transparent lines) to modulate the star images and determine relative star positions from the phase relationships of the modulated signals. This approach uses a multichannel detector system in which star images are individually detected.

The key element of the measurement is the Ronchi ruling, which acts as a meter stick against which the star field is measured. The ultimate ability of the instrument to meet the ATF astrometric requirements rests on the stability of the grating. Uniform expansion or contraction of the ruling does not affect the final measurements (as a scale change cancels out when the target and reference stars are compared) and small random errors in the position of the ruling lines will average out because the final measurement consists of an average over many thousands of line passages across the image. Present ruling technology is capable of producing rulings of the required quality. This approach can be implemented in a manner which makes it insensitive to photometric nonuniformity of the detectors. A multichannel detector instrument of this type, employing positionable detector pickups with the positioning accuracy required for the ATF mission, is in use at the Steward Observatory.

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
RONCHI RULING CONCEPT

- APPROACH
  - STAR IMAGE MODULATED AT TELESCOPE PRIME FOCUS BY MOVING RONCHI RULING
  - RELATIVE STAR POSITION DEFINED BY PHASE DIFFERENCES OF MODULATED SIGNALS
  - HIGHLY DIFFERENTIAL MEASUREMENT
    - STAR POSITIONS REFERRED TO RIGID "METER STICK" (RULING)
    - TARGET STAR REFERRED TO REFERENCE STARS
    - FOR PLANETARY DETECTION, ONLY INTERESTED IN CHANGES IN POSITION
- REQUIREMENTS
  - RONCHI RULING DIMENSIONAL ACCURACY: 0.05μ
  - MOTION RATE STABILITY: 0.01%
  - LARGE NUMBER OF CYCLES: 10^3 - 10^4
  - MULTICHANNEL DETECTOR SYSTEM

<u>3.1.2-2 Ronchi Ruling Concept (Contd)</u>. - This page intentionally left blank.

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
RONCHI RULING CONCEPT (CONTD)

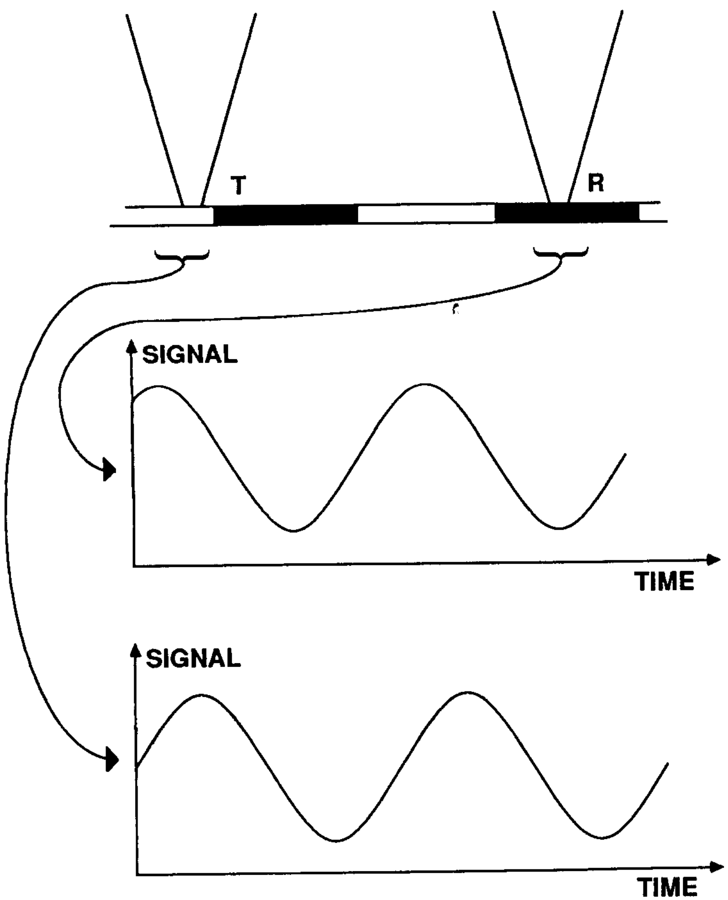
- IMPLEMENTATION
  - RONCHI RULING OF REQUIRED QUALITY WITHIN PRESENT MANUFACTURING CAPABILITIES
  - MULTI-CHANNEL DETECTION SYSTEM WITH POSITIONABLE PICKUPS IN OPERATION AT STEWARD OBSERVATORY

3.1.3 Ronchi Ruling Approach Description. - Located in the focal plane, the grating is moved in the direction perpendicular to the long dimension of the strips. The light from each star is thus modulated -- alternately blocked and transmitted.

To make a quantitative determination of the stellar positions, the light from each star is collected and the corresponding intensity is measured as a function of time. The modulated signal is sensitive to the location of the star, a displacement of the image (in the direction of the grating motion) produces a time-shift in the modulated signal. Thus the position of a star can be sensed by measuring the phase of its modulated light curve.

In general one is determining the distance between the target star image and those of a number of nearby reference stars. The separation of any two images can be determined if the phase measurement described above is made for both images, and if the distance between them is known to the nearest whole number of grating lines. The final reduction is a modestly complex operation that ties together the information provided by the images of the target star and the reference stars. The use of multiple reference stars improves the accuracy and reliability of the measurement.

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
RONCHI RULING APPROACH DESCRIPTION



- PRIMARY OPTICS FORMS IMAGES OF TARGET STAR (T) AND REFERENCE STAR (R) IN THE FOCAL PLANE
- MOVING RONCHI RULING ALTERNATELY BLOCKS AND TRANSMITS STARLIGHT
- DETECTORS SEPARATE LIGHT FROM STARS
- MODULATED SIGNAL CURVES CONTAIN POSITIONAL INFORMATION ENCODED AS PHASE OF SIGNALS
- POSITION DIFFERENCE (T-R) EQUALS PHASE DIFFERENCE + KNOWN NUMBER OF GRATING STEPS

3.2 Idealized Performance

3.2.1 Performance Overview. - The ideal limit set by optics and the nature of light cannot be achieved in practice as there are several ways in which information is lost by the system. These inefficiencies include: light losses at various points in the optical train; random errors which effectively dilute the astrometric information and increase the integration time needed to achieve a given level of accuracy (e.g., random errors in the drive rate of the ruling); and such factors as the limitation to work on one of the two coordinates (X and Y) at a time (a 50% efficiency compared to the ideal system) and the "down time" of the system. All of these decrease the rate at which useful astrometric information is actually obtained by the system and can largely be compensated for by increasing the integration time. Systematic errors, on the other hand, by definition do not average out and must be eliminated or calibrated out.

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
PERFORMANCE OVERVIEW

- FUNDAMENTAL ACCURACY LIMIT SET BY
  - PHOTON STATISTICS
  - TELESCOPE IMAGING PERFORMANCE
- THE FOLLOWING INEFFICIENCIES CAN BE COMPENSATED FOR BY INCREASING INTEGRATION TIME
  - LIGHT LOSSES (QUANTUM EFFICIENCY OF VARIOUS SYSTEM PARTS)
  - OTHER INFORMATION LOSSES (E.G., OPERATIONAL INTERRUPTIONS)
  - RANDOM ERRORS
- SYSTEMATIC ERRORS MUST BE AVOIDED OR REMOVED
- OVERALL OBSERVATION TIME REQUIRED IS DETERMINED BY BRIGHTNESS OF THE STARS, LIGHT AND OTHER INFORMATION LOSS EFFECTS, AND THE MAGNITUDE OF THE RANDOM ERRORS

3.2.2 Measurement Accuracy: Fundamental Limits. - Because of diffraction effects, the ideal performance of any astrometric system is limited by photon statistics.

There is always an error in a measured star position (as determined with a finite number of photons) because of the statistical nature of the way photons are distributed in the image. This is the most fundamental source of error because it is utterly unavoidable. That is, even an ideal position determining device, given that N photons arrive from a star, is subject to a random error which decreases inversely with the squareroot of N. In fact, if the profile of the star image is given by a function f(x), and if the width of the image is denoted by the standard deviation

$$\sigma_o = \sqrt{\int f(x)(x-\langle x\rangle)^2 dx},$$

where <x> is the centroid position, then we have the following expression for the variance in position (i.e., rms error):

$$\sigma = \sigma_o/\sqrt{N}$$

The image size (σ_o) of a diffraction limited 1-m telescope in space is about 0.1 arcsec at visual wavelengths. The desired astrometric accuracy per measurement (σ) is 0.00001 arcsec, as derived from the science requirements. These two numbers and the last equation immediately yield the number of photons needed, ideally, to achieve this accuracy: 10^8 photons.

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
MEASUREMENT ACCURACY: FUNDAMENTAL LIMITS

- MEASUREMENT ACCURACY LIMITED BY:
  - PHOTON STATISTICS
  - DIFFRACTION
- NO TELESCOPE DESIGN CAN EXCEED THE FOLLOWING ACCURACY LIMIT:

$$\sigma = \sigma_0 / \sqrt{N}$$

WHERE: σ = IDEAL MEASUREMENT ACCURACY
σ_0 = IMAGE SIZE

AND: N = TOTAL NUMBER OF PHOTONS ACCUMULATED

NOTE: THE DEPARTURE OF THE ACTUAL IMAGE SIZE/SHAPE FROM THE DIFFRACTION LIMIT IS DISCUSSED UNDER "RANDOM ERRORS"

3.3 Light Loss Effects

The listed inefficiencies (sources of information loss) all mean that the integration time needed to count a fixed number of photons (and therefore achieve a given astrometric accuracy) is increased. Some items (A, B, D, and E) are direct losses of light at various points in the optical system. Others are information losses (compared to an ideal system). The loss labeled "grating intrinsic" (C) arises from the fact that the very act of running edges across the star images, although necessary to make the measurements accurate and the system robust, does result in the loss of some astrometric information present in the original image. This is in addition to the 50% light loss because of the grating blockage (A), and can be thought of as the result of differentiating a noisy signal. The loss depends on how the data are reduced, and the 50% figure shown is based on simulations with the best algorithm discovered so far.

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
LIGHT LOSS EFFECTS

- INTEGRATION TIME NEEDED TO REACH A GIVEN ACCURACY IS INCREASED BY LIGHTAND OTHER INFORMATION LOSSES

SOURCE OF INFORMATION LOSS	TYPE OF LOSS	THROUGHPUT
A. GRATING REJECTION	LIGHT	0.25
B. MASK FOR GRATING SHADOW	LIGHT	0.75
C. GRATING INTRINSIC	INFORMATION	0.50
D. LOSS IN OPTICS	LIGHT	0.50
E. DETECTOR QUANTUM INEFFICIENCY	LIGHT	0.10
F. ONE-DIMENSIONAL ENGINE	INFORMATION	0.50
G. OPERATIONAL INTERRUPTIONS	INFORMATION	0.50
	TOTAL THROUGHPUT	0.00117

INTEGRATION TIME INCREASED BY 1/THROUGHPUT = 853

3.4 Error Analysis

3.4.1 Systematic Errors.

3.4.1.1 Measurement Accuracy — Systematic Errors: One of the major advantages of space over the ground as a platform for astrometry is that the disturbing effects of the Earth's atmosphere are absent. Thus smaller images and the absence of random "seeing" effects are achieved, and in addition, systematic errors connected with color-dependent refraction in the atmosphere are totally absent in space.

The design of the ATF must be such as to minimize the residual systematic effects intrinsic to the H/W. This task is greatly simplified due to the differential nature of the measurement.

3.4.1.2 Potential Systematic Errors: This chart lists the potential systematic errors that have been identified and studied in a preliminary way. Approaches for minimizing and/or correcting the errors are indicated in the "solution" column.

Color coma refers to the wavelength dependence of the star image shape (and therefore of its centroid) resulting from the combined effects of diffraction and coma. The measurement approach suggested for ATF includes making observations in two separate bandpasses so that any wavelength-dependent shift can be measured and removed from the data.

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
MEASUREMENT ACCURACY: SYSTEMATIC ERRORS

- THE SPACE ENVIRONMENT IS FREE OF MOST SOURCES OF SYSTEMATIC ERROR KNOWN FROM GROUND-BASED WORK
- THE TELESCOPE DESIGN IS ORIENTED TOWARD MINIMIZING THE POTENTIAL SYSTEMATIC ERRORS
- THE RELATIVE NATURE OF THE MEASUREMENT RESISTS SYSTEMATIC ERRORS
  - STAR RELATIVE TO GRATING EDGES
  - TARGET STAR RELATIVE TO REFERENCE STARS
  - MEASUREMENT INVARIANT TO LINEAR SCALE CHANGES
  - LOOKING FOR CHANGES IN POSITION, NOT POSITION ITSELF

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
POTENTIAL SYSTEMATIC ERRORS

EFFECT	SOLUTION
OPTICAL SURFACE VARIATIONS	USE ONE OPTICAL SURFACE IN ENTRANCE PUPIL
COMA	OPTIMIZED RULING — TWO COLOR BANDS
CHANGES OF MIRROR COATING	OVERCOAT TO HOLD WITHIN SPECS AND PROTECT FROM CONTAMINATION
NONUNIFORM RULING DEFORMATION	MATERIAL SELECTION AND STATISTICAL TESTING
TRANSMISSION CHANGES OF SECONDARY OPTICS (RULING, OPTICAL FIBERS, ETC.)	MATERIAL SELECTION
FIELD CROWDING	EXAMINATION OF FIELDS FOR OPTICAL DOUBLES
UNKNOWN NONLINEAR REFERENCE STAR MOTIONS	SELECTION OF DISTANT REFERENCE STARS AND CONTINUOUS MODELING

3.4.2 Random Errors.

3.4.2.1 Measurement Accuracy — Random Errors: Random errors increase the integration time required for a specified accuracy. If several sources of random error are present, the variances (σ^2) from the errors add together to produce the effective total variance (this assumes independence of the individual error sources). For convenience, in this table, the individual sources are expressed relative to the variance due to photon statistics. To estimate the combined effect of the several sources of random error, one simply adds together the ratios of the individual error variances to the photon statistics variance (called "F" in the table), including 1 for photon statistics itself. The total effective variance is the photon statistics variance multiplied by the sum of the individual F ratios.

The largest increase over photon statistics (entry 1) is the effect of increased image size caused by coma near the edges of the field (entry 3). Although this is strictly speaking not a random error for a given star, it depends on the position of the reference star and the orientation of the ruling scan relative to the coma axis, and is thus effectively random.

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
MEASUREMENT ACCURACY: RANDOM ERRORS

- INTEGRATION TIME NEEDED TO REACH A GIVEN ACCURACY IS INCREASED BY RANDOM ERRORS

	ERROR SOURCE	F*
1.	PHOTON STATISTICS (σ_o)	1.000
2.	BACKGROUND LIGHT	.002
3.	IMAGE SHAPE/SIZE	.30
4.	IMAGE MOTION (JITTER)	(a)
5.	GRATING IMPERFECTIONS	(a)
6.	GRATING MOTIONS	(b)
7.	GRATING ALIGNMENT	TBD
8.	FIELD MODELING	0.060
9.	REDUCTION ALGORITHM	<< 1
10.	POSTFOCAL RESPONSE VARIATION	TBD
11.	REFERENCE STAR ERRORS	(c)
12.	CONTAMINATION	TBD

TOTAL TIME FACTOR: 1.362 + TBD

*F = CONTRIBUTION TO THE INTEGRATION TIME ENHANCEMENT FACTOR; TOTAL TIME ENHANCEMENT IS THE SUM OF THE INDIVIDUAL F'S.

NOTES:
(a) THE DESIGN REQUIREMENT CORRESPONDING TO F << 1 IS FEASIBLE.
(b) INCLUDED IN JITTER.
(c) WITH PROPER SELECTION OF FIELDS AND REFERENCE STARS THIS ERROR WILL BE NEGLIGIBLE (F << 1).

3.4.2.2 Sensitivity of ATF to "Jitter": Of the known sources of random error, image jitter deserves particular attention. A special advantage of the moving grating measurement technique is that it is largely insensitive to random or otherwise uncontrolled motions of the telescope. However, it is quite sensitive to coherent jitter in a very narrow band (±0.1 Hz) about the modulation frequency, its harmonics, and its subharmonics. Grating frequencies can be chosen to avoid system jitter.

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
SENSITIVITY OF ATF TO "JITTER"

- MOVING GRATING TECHNIQUE FUNDAMENTALLY INSENSITIVE TO JITTER
  - STRICTLY RELATIVE MEASUREMENT
  - TARGET/REFERENCE STARS AFFECTED IN SAME WAY BY POINTING DISTURBANCES

- THE EFFECT OF RANDOM OR PERIODIC DISTURBANCES DEPENDS ON THE TIME SCALE OF THE MOTION:
  - SLOW JITTER:
    - JITTER FREQUENCY << GRATING MODULATION FREQUENCY
    - CANCELS OUT WHEN DATA REDUCED
  - FAST JITTER:
    - JITTER FREQUENCY >> GRATING MODULATION FREQUENCY
    - DOES NOT INTRODUCE SYSTEMATIC ERROR
    - RANDOM ERROR INSIGNIFICANT WHEN JITTER AMPLITUDE < 0.1 ARCSEC
  - INTERMEDIATE JITTER:
    - JITTER FREQUENCY ≈ GRATING MODULATION FREQUENCY
    - ONLY CONCERN IS AT A SMALL NUMBER OF RESONANCES
    - JITTER AMPLITUDE MUST BE < 0.01 ARCSEC IN THESE NARROW BANDS
    - COHERENT NOISE RESONANCES ELIMINATED BY PHASE RANDOMIZATION

3.4.2.3-1 Measurement Accuracy — Jitter Analysis: A "Monte Carlo" simulation of the entire telescope system (starting with the incoming light, and ending with the simulated data stream) has been used to study the effects of jitter on the measurements.

The major sensitivity of the moving-ruling system is a resonance when the frequency of the jitter matches the frequency at which the grating edges cross a star image. Since there are two edges per ruling period, this is twice the ruling modulation frequency. This resonance is significant only if the two frequencies are very precisely constant (and equal) over the several minutes required for a scan. Irregularities in both frequencies have been shown to be very effective at breaking the resonance and causing the positional error to average out.

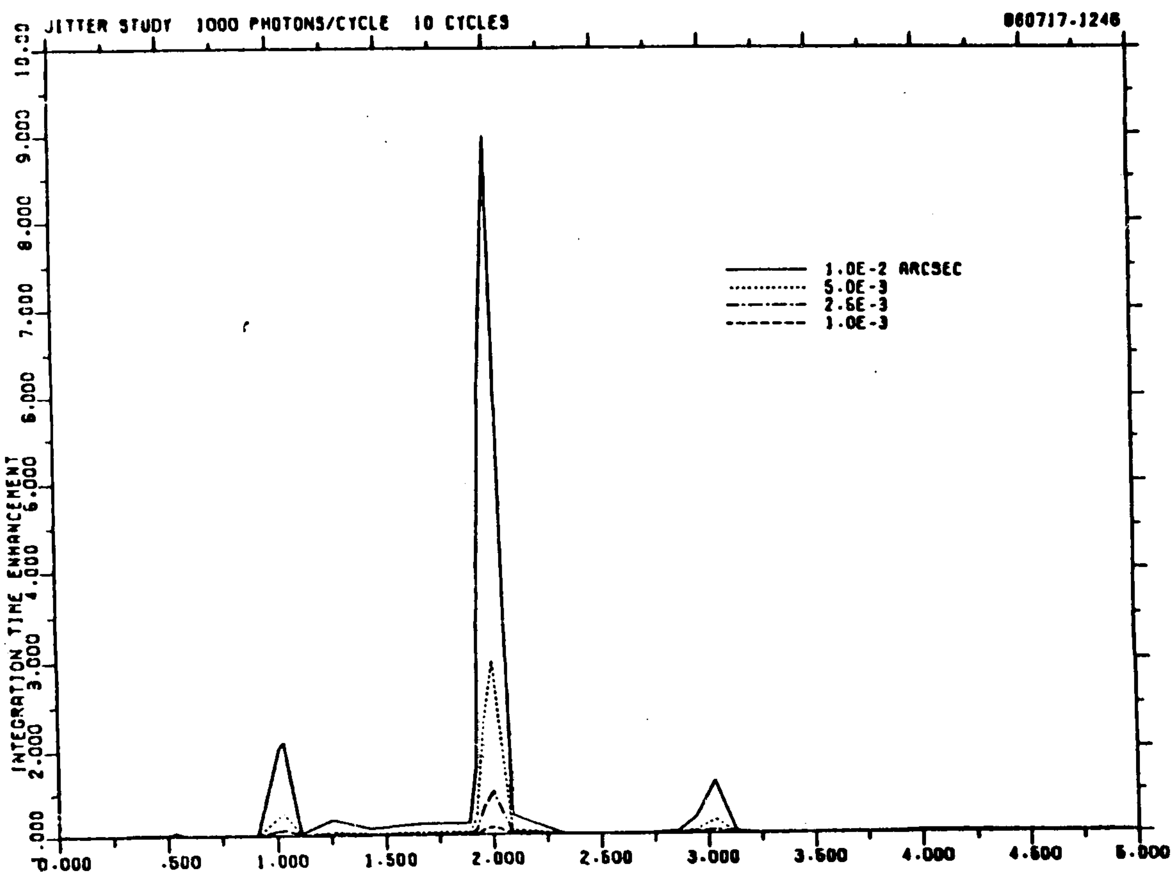
ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
MEASUREMENT ACCURACY: JITTER ANALYSIS

- APPROACH
  - MONTE CARLO SIMULATION
  - ARBITRARY MOTION OF IMAGE RELATIVE TO GRATING
  - JITTER MODELED AS SINUSOIDAL INPUT, WITH PHASE RANDOMIZATION
  - COMPUTE INTEGRATION TIME NEEDED TO REACH ACCURACY GOAL
- RESULTS
  - VERY SMALL EFFECT AT MOST FREQUENCIES
  - LARGEST EFFECT IS RESONANCE AT 2 X GRATING MODULATION FREQUENCY
  - SMALLER EFFECTS AT HARMONICS AND SUBHARMONICS OF GRATING FREQUENCY
  - VERY SMALL BANDWIDTHS AT THESE RESONANCES
  - RESONANCE WITH PHASE-STABLE JITTER DESTROYED BY TRACKING OR GRATING DRIVE ERRORS

3.4.2.3-2 Measurement Accuracy: Jitter Analysis — Integration Time versus Jitter Frequency: One of the results of the simulation study is shown here. The factor by which the integration time is increased because of the presence of jitter is plotted as a function of the frequency of the jitter. As the jitter amplitude increases (indicated by different line styles) the required integration time increases.

An important result is that the largest effect occurs at frequencies which are exact multiples of the grating frequency (the frequency at which the starlight is modulated by the passage of the ruling across the star images). By far the largest effect is at exactly twice the grating frequency, because this is the frequency with which edges cross the star images.

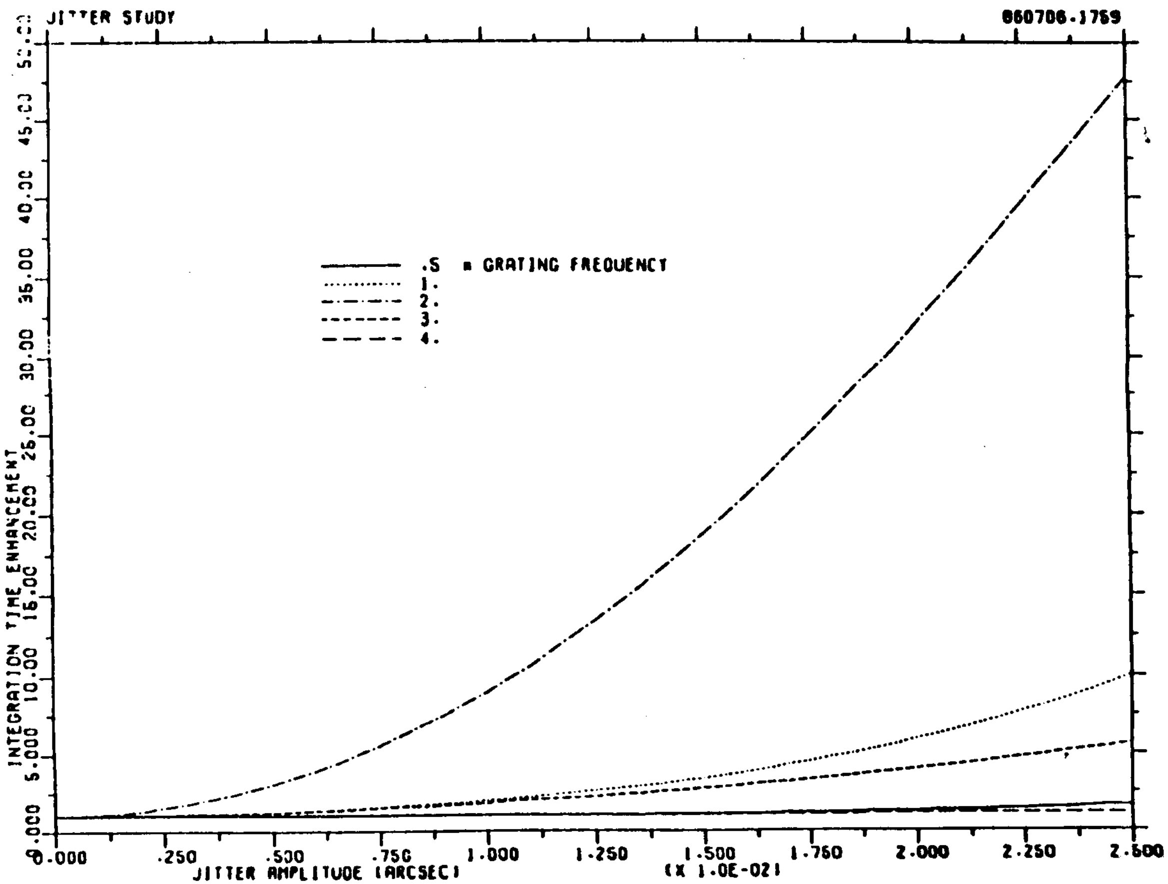
ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
INTEGRATION TIME VERSUS JITTER FREQUENCY



JITTER FREQUENCY / GRATING FREQUENCY

3.4.2.3-3 Measurement Accuracy: Jitter Analysis — Integration Time versus Amplitude: The integration time increase is plotted here as a function of the jitter amplitude. This view is useful when deriving a specification for the maximum jitter amplitude permissible (at various frequencies). The condition that the integration time not be increased by a given amount translates directly into a limit on the allowable jitter (see also the next plot).

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
INTEGRATION TIME VERSUS AMPLITUDE



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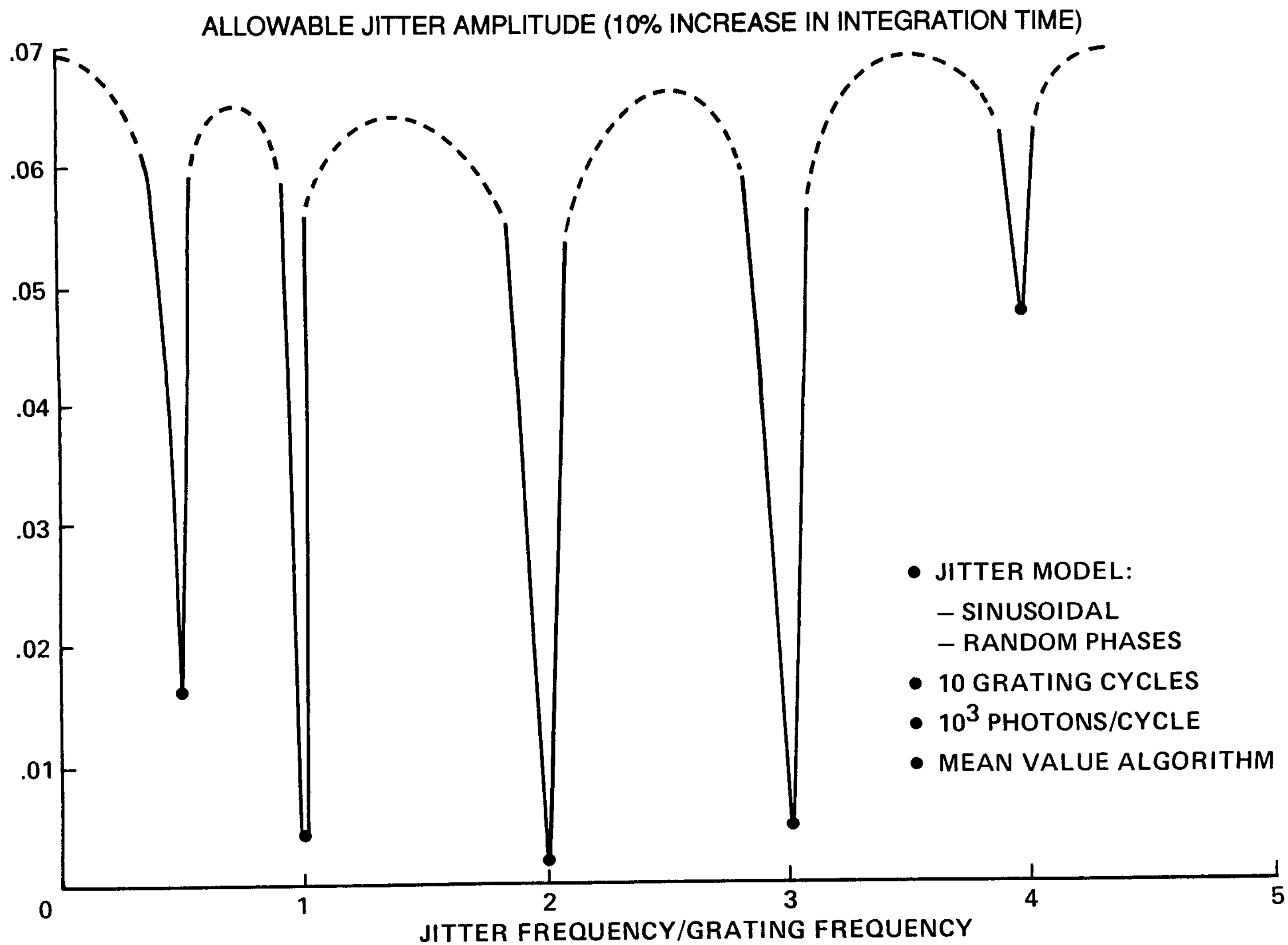
3.4.2.3-4 Measurement Accuracy: Jitter Analysis — Jitter Amplitude versus Frequency: The consideration discussed on the previous plot was used to derive this "allowable jitter spectrum."

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
JITTER AMPLITUDE VERSUS FREQUENCY



3.5 Observation Time Requirements

3.5.1 Ideal Integration Times. - This chart shows the variation of the average photon rate expected from the 32 brightest stars in a 10- by 10-arcmin field of view with galactic latitude (the smaller dependence on galactic longitude has been ignored). Shown are the integration times needed for a 1.25-m mirror to accumulate 10^8 photons, and not corrected for any inefficiencies, random errors, or systematic errors.

NOTE: The star magnitude values (and hence the total photon rate) for galactic latitudes of 0 and 10° can vary significantly with galactic longitude. Therefore, the mission analysis (section 8.0 was performed under the conservative assumption that the total photon rate does not improve below a galactic latitude of 20°).

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
IDEAL INTEGRATION TIMES

- THE INTEGRATION TIME IS SET BY THE NUMBER AND BRIGHTNESS OF THE REFERENCE STARS NEAR THE TARGET STAR
- THE DENSITY OF REFERENCE STARS DECREASES WITH INCREASING GALACTIC LATITUDE

REFERENCE FRAME PHOTON RATES AND IDEAL INTEGRATION TIMES
BASED ON GALACTIC MODEL BY BAHCALL AND SONEIRA
(CALCULATED FOR LONGITUDE 90°)

GALACTIC LATITUDE	STAR MAGNITUDES		TOTAL PHOTON RATE (PHOTONS/SEC)	IDEAL INTEGRATION TIME* (MIN)
	BRIGHTEST	32ND		
0°	8.1	11.8	5.5 X 10**7	0.030
10°	11.3	15.0	2.9 X 10**6	0.57
20°	12.3	16.0	1.2 X 10**6	1.37
30°	12.8	16.5	7.6 X 10**5	2.19
40°	13.2	16.9	5.3 X 10**5	3.12
50°	13.4	17.2	4.0 X 10**5	4.12
60°	13.7	17.4	3.3 X 10**5	5.00
70°	13.8	17.5	2.8 X 10**5	5.95
80°	13.9	17.6	2.7 X 10**5	6.25
90°	13.9	17.7	2.5 X 10**5	6.58

* THE INTEGRATION TIME SHOWN HERE IS FOR AN IDEAL SYSTEM WITH NO LOSSES.

3.5.2 Realistic Observation Times. - The total integration time can be estimated by correcting the ideal integration time for light/information losses and for random errors. The average time required for an observation is shown as a function of galactic latitude.

Note that the observation time requirement includes estimates for the down time of the system, time to slew between targets, target acquisition, and so on, and is therefore substantially longer than the time spent integrating on the star.

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
REALISTIC OBSERVATION TIMES

- TOTAL OBSERVATION = INTEGRATION TIME FOR IDEAL SYSTEM
  X
  TIME FACTOR FOR LIGHT AND INFORMATION LOSSES (853)
  X
  TIME FACTOR FOR RANDOM ERRORS (1.36)

- FOR ATF: OVERALL TIME FACTOR = 853 X 1.36 = 1160

  OBSERVATION TIME = 1160 X IDEAL INTEGRATION TIME

GALACTIC LATITUDE	IDEAL INTEGRATION TIME (MINUTES)	AVERAGE OBSERVATION TIME (HOURS)
0°	0.030	0.58
10°	0.57	10.98
20°	1.37	26.6
30°	2.19	42.4
40°	3.12	60.4
50°	4.12	80.6
60°	5.00	96.6
70°	5.95	115
80°	6.25	120.8
90°	6.58	127.2

MOST OBSERVATIONS AT LOW LATITUDES

3.6-1 Mission and System Requirements

For the purposes of Planetary Detection, it is required that each of the 100 stars be observed to an accuracy of 10 μarcsec at a minimum of once per year. The "realistic" observation time requirements shown in figure 3.5.2 as a function of galactic latitude, suggest that on average an observation will require approximately 60 hr. (This value represents an area weighted average based on an even distribution of stars, and assumes that the required observation time does not improve at galactic latitudes below 20°. This conservative assumption was made because the Bahcall-Soneira model is stated to be uncertain at low galactic latitudes.) Therefore, approximately 6000 hr/yr are required for Planetary Detection. By assigning two thirds of the facility time to Planetary Detection (5800 hr/yr), it should be possible to observe each star approximately once per year, providing for the minimum requirement. Further margin might also be achieved by selecting targets with better than average reference frames and by keeping to low galactic latitudes. Such a strategy still allows for nearly 3000 hr each year to be made available for general astrometry.

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS
MISSION AND SYSTEM REQUIREMENTS

- PLANETARY DETECTION - SCIENCE REQUIREMENTS
  - OBSERVE APPROXIMATELY 100 STARS FOR 20 YR
  - ACCURACY: 10 μARCSEC
  - NUBMER OF OBSERVATIONS/STAR: MINIMUM OF 20
- PLANETARY DETECTION - DERIVED SYSTEM REQUIREMENTS
  - OBSERVATION TIME REQUIRED/YR: 5800 HOURS, 2/3 OF AVAILABLE VIEWING (BASED ON 1.25 m DIA MIRROR, PROVIDES FOR 39 OBSERVATIONS/STAR)
  - FIELD OF VIEW: 10 ARCMIN

* "OBSERVATION" - MULTIPLE INTEGRATIONS COMBINED TO YIELD STATED ACCURACY FOR TARGET STAR POSITION

3.6-2 Mission and System Requirements (Contd)

The only significant difference between the requirements for general stellar astrometry and planetary detection astrometry are driven by the need to establish a zero-parallax reference frame, by having a background quasar in each field of view. To have a reasonable probability of finding a quasar, the field of view must be on the order of 10-20 arcmin.

Since quasars are relatively faint, it would not be possible to detect enough photons in reasonable observation times to obtain 10 μarcsec accuracy. However, many important scientific programs could be carried out using the accuracy which can be obtained, on the order of 100 μarcsec.

ASTROMETRIC MEASUREMENT DESCRIPTION AND REQUIREMENTS MISSION AND SYSTEM REQUIREMENTS (CONTD)

- GENERAL ASTROMETRY - SCIENCE REQUIREMENTS - SAME AS FOR PLANETARY DETECTION EXCEPT AS SHOWN BELOW

  - ACCURACY: 100 μARCSEC

- GENERAL ASTROMETRY - DERIVED SYSTEM REQUIREMENTS

  - FIELD OF VIEW: 10-20 ARCMIN

4.0 MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS

4.1-1 ATF Mission/System Overview

This section presents an overview of the ATF mission and system characteristics. Subsequent sections of this report will cover each item in more detail.

The ATF is a candidate IOC payload for the SS, thus the specific launch dates are dependent on SS schedules. As so far as can be determined from this study, there are no technological advances required by ATF which would preclude ATF from meeting an early-to- mid 1990's launch date.

The 20-yr mission life is required to observe target star motions for times commensurate with orbital periods of representative intermediate sized planets. The optical configuration selected for the strawman design consists of a single mirror, parabolic telescope, with a moving Ronchi ruling at the prime focus. After the prime focus, the light is transferred to the side of the tube and reimaged in the FPI (covered on the next chart).

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF MISSION/SYSTEM OVERVIEW

- LAUNCH
  - EARLY-TO-MID 1990'S
  - SECTIONED FOR PACKAGING IN STS CARGO BAY
  - REQUIRES ON-ORBIT ASSEMBLY
- MISSION DURATION
  - 20 YR
  - MAINTENANCE FREQUENCY $\geq$ 5 YEARS
- CAPABILITIES
  - 10 μ ARCSEC MEASUREMENT ACCURACY (RELATIVE TO REFERENCE STARS)
  - DETECT INTERMEDIATE SIZED PLANETS (10$\oplus$) ABOUT STARS WITHIN APPROXIMATELY 10 PARSECS
- OPTICAL CONFIGURATION
  - SINGLE MIRROR SYSTEM
  - RONCHI RULING AT PRIME FOCUS
  - DIAGONAL/RELAY LENSES DIRECT IMAGE TO SIDE OF TUBE
  - 1.25 m APERTURE
  - F/D = 13
  - FIELD SIZE AT FOCAL PLANE 47.3 mm

4.1-2 ATF Mission/System Overview (Contd)

The SS configuration and the design of the SS CPS have not been firmly established. A variety of SS mounting options have been investigated; the preferred ATF mounting location is on the aft side of the SS upper science boom. A unique mounting arrangement is required to achieve the required viewing angles because of the length of the ATF.

The graphite epoxy tube was selected to provide the necessary dimensional stability in response to dynamic disturbances and orbital temperature variations. The selected material has a near zero axial coefficient of thermal expansion.

The focal plane instrument selected for the current ATF design is a "medusa" type instrument similar to the one now in use at the Steward Observatory in Arizona.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF MISSION/SYSTEM OVERVIEW (CONTD)

- MOUNT/POINTING
  - MOUNTED ON SS UPPER SCIENCE BOOM
  - USES SS COARSE POINTING SYSTEM
  - VIEWING IN AFT HEMISPHERE
  - ATF PROVIDES VERNIER POINTING TO 1 ARCSEC
  - ATF PROVIDES ROLL ADJUSTMENT (LIMITED REALTIME CONTROL)
  - ATF PROVIDES VIBRATION ISOLATION
- PHYSICAL CHARACTERISTICS
  - GRAPHITE/EPOXY TUBE
  - 1.85 m DIA x 21.5 m LONG TUBE
  - VIBRATION ISOLATION SYSTEM 4 m DIA
  - 6420 kg LAUNCH MASS
  - 1408 W AVERAGE POWER
- FOCAL PLANE INSTRUMENT
  - 0.4 μ TO 0.8 μ SPECTRAL RANGE
  - 32 INDIVIDUAL STAR IMAGE PICKUPS (FIBER OPTICS)
  - PHOTOMULTIPLIER TUBE (PMT) DETECTORS
  - 2.5 X MAGNIFICATION OF FIELD BY RELAY LENS

4.1-3 ATF Mission/System Overview (Contd)

The heart of the ATF is the Ronchi ruling. The ruling is mounted at the prime focus of the telescope and is moved slowly back and forth (lines perpendicular to motion) across the field of view, modulating the signal from the stars in the field. As discussed in section 3.0 the relative phase of these signals can be used to determine relative motions of stars to a very high accuracy.

The prime safing feature of the ATF is its aperture cover. Should a specified sun-avoidance criteria be violated or a power outage occur, the door will automatically close and remain closed until opened by ground command. In addition, the cover will be closed by command for maintenance operations and when major contamination events are planned by the SS.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF MISSION/SYSTEM OVERVIEW (CONTD)

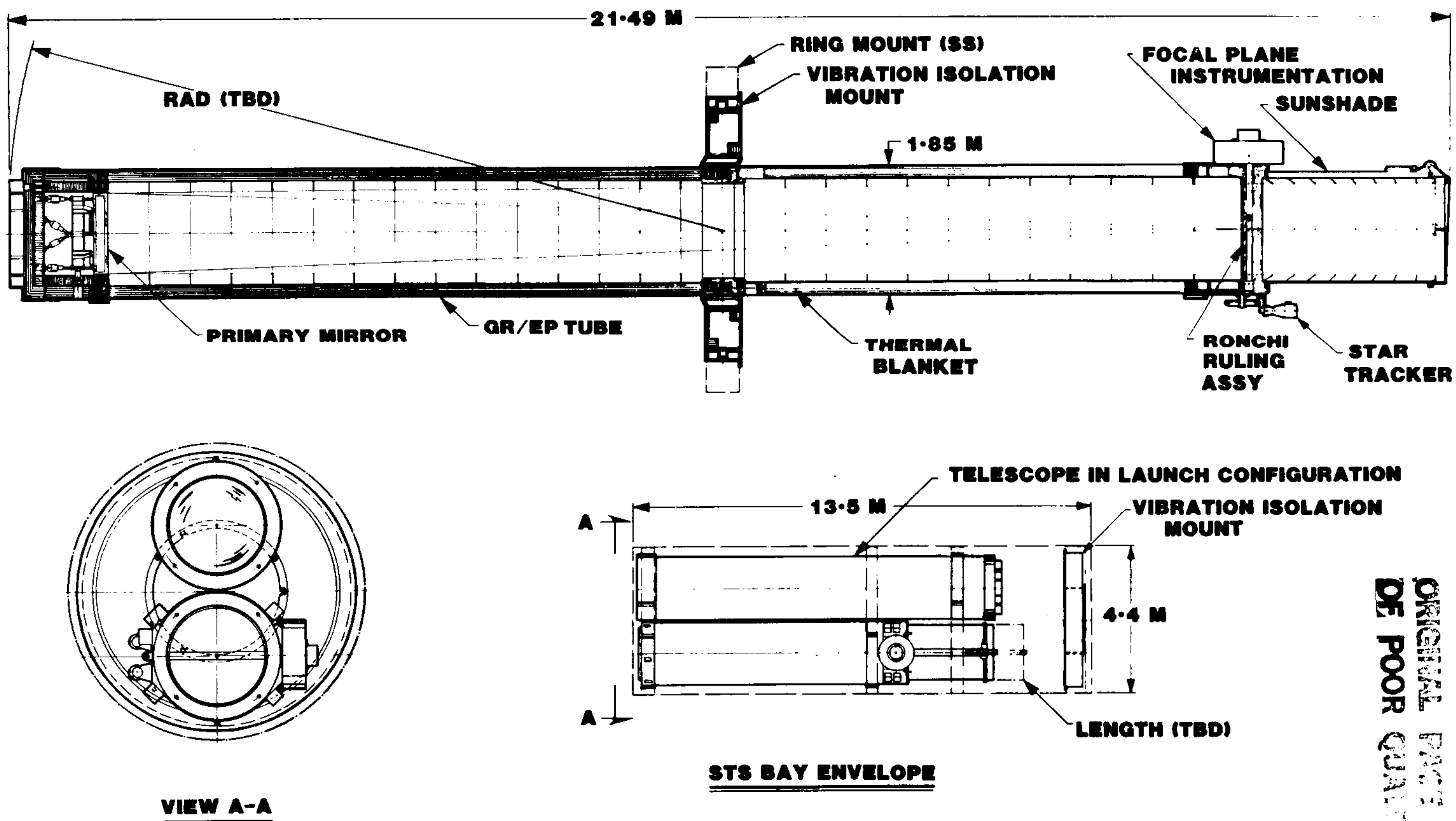
- RONCHI RULING
  - TRANSMISSION, 10 LINES/mm
  - 48 x 600 mm
  - 10 TO 100 LINE PAIR/SEC SCAN RATE
- MISSION OPERATIONS
  - VIEWS ≈ 100 NEARBY TARGET STARS
  - OPERATION AUTOMATIC USING STORED SEQUENCES
  - PERIODIC UPLINK OF SEQUENCES
  - NORMALLY PROCESS DATA ON GROUND
  - REAL TIME DATA RATE 1.75 Mbps (MAXIMUM)
  - AUTOMATIC SAFING FOR SYSTEM CRITICAL EVENTS
  - CONTINGENCY CONTROL ACCESS VIA CONTROL CONSOLE
  - VERY FLEXIBLE VIEWING SCENARIOS

4.2 Astrometric Telescope Facility (ATF)

This figure shows the ATF in its assembled and launch configurations. The overall dimensions of the ATF telescope tube are 21.49 m long by 1.85 m diameter. The maximum diameter at the centrally located vibration isolation system which mounts to the SS CPS is 4 m. The ATF will be CG mounted in the CPS. The swing radius on the top section of the figure is labeled TBD and will be defined at the end of the H/W development phase (System CDR) to place the CG at the CPS interface. Current estimates are that the telescope CG will be located 10.6 m from the aft end.

The ATF is divided into 3 sections for launch packaging as shown on the bottom half of the figure. The tube sections are split at the mounting location of the vibration isolation system (at telescope CG). The package length is labeled TBD for the reasons cited above. The allowable STS packaging dimensions for the ATF are 4.4 m diameter by 13.6 m long. The ATF requires an essentially dedicated shuttle launch because of its high volume to mass ratio.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ASTROMETRIC TELESCOPE FACILITY (ATF)



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4.3 ATF Hardware Elements

This figure lists the various H/W elements that make up the total ATF system. The ATF electronics are mounted on the telescope to reduce the number of wires that would have to cross the CPS. The SS provided CPS is included on this list for completeness.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF HARDWARE ELEMENTS

- TELESCOPE ASSEMBLY
  - TELESCOPE, FOCAL PLANE INSTRUMENT (FPI), ELECTRONICS (SEPARATE ELECTRONICS PALLET CONSIDERED FOR MIDTERM HAS BEEN DELETED)
- VIBRATION ISOLATION ASSEMBLY
  - VIBRATION ISOLATION SYSTEM, ROLL ANGLE ADJUST SYSTEM, VERNIER POINTING SYSTEM
- ATF CONTROL CONSOLE
  - ENGINEERING DATA PROCESSOR, ASTRONAUT/ATF INTERFACE, SS INTERACTIVE TERMINAL INTERFACE
- AIRBORNE SUPPORT EQUIPMENT (ASE)
  - STRUCTURE TO SUPPORT TELESCOPE SECTIONS IN STS, STRUCTURE TO SUPPORT VIBRATION ISOLATION ASSEMBLY IN STS
- OPERATIONS SUPPORT EQUIPMENT
  - GROUND SUPPORT EQUIPMENT, FLIGHT SUPPORT EQUIPMENT, MISSION OPERATIONS EQUIPMENT
- POINTING MOUNT
  - A CPS PROVIDED BY THE SS

4.4-1 ATF Mission Requirements/Characteristics

This and the subsequent system section (sections 4.4 and 4.5) contain the top level mission and system requirements and characteristics. A summary list of requirements and characteristics defined by the study is contained in volume 1, appendix A. Sections 5.0 and 6.0 provide detailed descriptions of the strawman H/W at the subsystem level.

The ATF mission length is driven by the need to observe the target stars for a period commensurate with anticipated planetary system orbital periods. Based on the only known model, our own solar system, 20 yr has been selected. The system requirement for unit life is 5 yr to be consistent with the qualified life of existing H/W. This approach is feasible because of the practicability of H/W replacement on the SS and avoids very expensive programs to qualify H/W for 20 yr. However, it does mean that some on-orbit replacement of failed units will probably be required.

A block redundant system has been selected for the strawman ATF design. Should a failure occur, a switch would be made to the redundant string and operation would continue until the required maintenance could be scheduled. Should a failure occur in an optical element such as the main mirror or the relay optics (e.g., major contamination) the ATF would have to be brought back to Earth to be refurbished.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF MISSION REQUIREMENTS/CHARACTERISTICS

REQUIREMENT	DESIGN	COMMENTS
• LAUNCH DATE - 1992 OR LATER	- THE ATF USES CURRENT TECHNOLOGY	- CANDIDATE FOR SS IOC, DATE DEPENDENT ON SS SCHEDULE
• LAUNCH VEHICLE - STS FROM KSC - SATISFY STS REQMTS	- THE ATF IS DIVIDED INTO 3 MAJOR SECTIONS FOR LAUNCH PACKAGING	- REQUIRES ON-ORBIT ASSEMBLY
• OPERATIONAL ORBIT - SS ORBIT COMPATIBLE	- THE SS IS USED AS A MOUNTING PLATFORM	- APPROXIMATE ORBIT PARAMETERS 463 TO 555 km ALTITUDE 28° INCLINATION
• MISSION LIFE - 20 YEARS	- A 5 YR MINIMUM LIFE FOR ACTIVE ELEMENTS	- REQUIRES LONG LIFE TO OBSERVE PLANETARY PERTURBATIONS OF STAR POSITIONS
	- PASSIVE ELEMENTS INCLUDING OPTICS DESIGNED TO FUNCTION FOR 20 YR	- LONG LIFE FOR PRIMARY MIRROR AND RONCHI RULING IMPORTANT FOR METRICS CONTINUITY
	- BLOCK REDUNDANCY WITH CROSS-STRAPPING OF FPI USED	- ATF OPERATION IS FAILURE TOLERANT, CAN FUNCTION WHILE AWAITING MAINTENANCE, EXPECTED PERIOD BETWEEN MAINTENANCE > 5 YR
	- THE ATF USES ON-ORBIT MAINTENANCE TO ACHIEVE MISSION LIFE AS REQUIRED	

4.4-2 ATF Mission Requirements/Characteristics (Contd)

All environments have been considered in the ATF strawman design. Conservative design approaches have been selected wherever possible. Any mechanical distortions caused by on-orbit assembly and operation can be offset by commandable adjustments of the primary mirror and post-focal plane optics. Contamination is a major source of concern. Totally enclosed post-focal-plane optical elements are used along with an aperture door which is closed by command or in the event of an anomaly.

A fixed symmetrical sunshade has been selected to simplify the front end design of the telescope.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF MISSION REQUIREMENTS/CHARACTERISTICS (CONTD)

REQUIREMENT	DESIGN	COMMENTS
• MISSION ENVIRONMENTS		
- SURVIVE AND FUNCTION AS REQUIRED IN ALL MISSION ENVIRONMENTS INCLUDING: GROUND HANDLING AND TEST LAUNCH/ABORT/LANDING ON-ORBIT ASSEMBLY SS ENVIRONMENTS ON-ORBIT NATURAL ENVIRONMENTS SERVICING/RECOVERY	- THE USE OF ADEQUATE DESIGN MARGINS - ENCLOSED POST FOCAL PLANE OPTICS - OPERATIONS PROCEDURES TO MINIMIZE EXPOSURE - CAPABILITY FOR ON-ORBIT FOCUS ADJUSTMENTS	
• STRAY LIGHT		
- MINIMIZE STRAY LIGHT	- PROVIDE SUNSHADE AND TUBE BAFFLING - CONSTRAINED POINTING SEQUENCES	- FIXED SYMMETRICAL SUNSHADE USED

4.4-3 ATF Mission Requirements/Characteristics (Contd)

The majority of the favored fields for planetary detection are located near the galactic equator, however other objects of interest are located in the remaining portion of the celestial sphere. Hence, full sky coverage is required by ATF. The bright object avoidance angles shown on this figure were selected primarily on the basis of maximum length of fixed sunshade plus telescope tube that could be packaged in the STS. The sunshade was sized to prevent direct sunlight from striking the internal FPI/Ronchi ruling assembly. The Ram velocity avoidance angle was selected to minimize contamination and atomic oxygen interactions. The last two items (labeled TBD) represent effects which will have to be considered when the SS configuration and contamination environment are better defined.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF MISSION REQUIREMENTS/CHARACTERISTICS (CONTD)

REQUIREMENT	DESIGN	COMMENTS
• SKY COVERAGE		
- PROVIDE FULL SKY COVERAGE CONSTRAINED ONLY BY BRIGHT OBJECT AVOIDANCE CONES, SS OBSTRUCTIONS, AND CONTAMINATION AVOIDANCE	- USES SS PROVIDED CPS - BRIGHT OBJECT AVOIDANCE CONES: SUN ANGLE ≥ 30° EARTH LIMB ANGLE ≥ 30° (FOR EARTH LIMB ALTITUDE = 12 KM) MOON ANGLE ≥ 10° - RAM (VELOCITY) VECTOR AVOIDANCE ANGLE ≥ 90° - CONTAMINATION RETURN FLUX AVOIDANCE ANGLE IN THE ANTI-RAM DIRECTION ≥ TBD - SS OBSTRUCTION AVOIDANCE ANGLE ≥ TBD	- ADDITIONAL RESTRICTIONS MAY BE IMPOSED BY ATF MOUNTING LOCATION - GIMBAL LOCK ON SS CPS MAY RESTRICT SKY COVERAGE

4.4-4 ATF Mission Requirements/Characteristics (Contd)

The current strawman ATF has been designed primarily on the basis of planetary detection requirements, however it is capable of performing a variety of astrophysics investigations (discussed in section 2.0).

In order to detect relatively small planets about stars to 10 parsecs distance, a stringent measurement accuracy requirement is placed on ATF. Detailed analyses are required to determine the effect of error sources on measurement accuracy. Current estimates have indicated that the desired measurement accuracy requirements can be met for the required number of target stars within the available observing time limits. The analyses and assumptions defining the time to make measurements of the required accuracy are discussed in section 3.0. Section 8.0 shows that under these assumptions the strawman system on the SS can meet the observation time requirements.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF MISSION REQUIREMENTS/CHARACTERISTICS (CONTD)

REQUIREMENT	DESIGN	COMMENTS
• SKY SURVEY		
- PLANETARY DETECTION: PERFORM ASTROMETRIC MEASUREMENTS ON ≈ 100 NEARBY TARGET STARS. VISUAL MAGNITUDE OF TARGET STARS BETWEEN -1.5 AND +13.5, REFERENCE STARS TO +15	- DESIGN ACCOMMODATES "STRAWMAN" PLANETARY DETECTION TARGET STAR LIST OF > 100 STARS	- STRAWMAN ATF HAS BEEN DESIGNED TO SATISFY PLANETARY DETECTION REQUIREMENTS
- ASTROPHYSICS TBD		- ASTROPHYSICS INVESTIGATIONS REQUIREMENTS TO BE WITHIN CAPABILITIES OF SYSTEM DESIGNED FOR PLANETARY DETECTION
• MEASUREMENT ACCURACY		
- PLANETARY DETECTION < 10μ ARCSEC	- TBD (ANALYSIS OF MEASUREMENT ERRORS IS CONTINUING)	- DESIRED ACCURACY PERMITS THE DETECTION OF SINGLE OR MULTIPLE PLANETS OF MASSES GREATER THAN 10 EARTH MASSES ABOUT TARGET STARS WITHIN ABOUT 10 PARSECS
- ASTROPHYSICS < 100μ ARCSEC TBD		

4.4-5 ATF Mission Requirements/Characteristics (Contd)

To determine perturbations of target stars along some arbitrary line in space, astrometric measurements about two orthogonal axes are required. To minimize systematic errors, measurements are required in the plus and minus directions for both the x and y axes. To accommodate these requirements, the telescope tube must roll ±180°.

The minimum tracking period is determined on the basis of the time required for one sweep of the ruling across the field of view at its fastest rate plus some margin for setup and stabilization. It is required that a minimum of one full sweep of the ruling be obtained for each observational segment.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF MISSION REQUIREMENTS/CHARACTERISTICS (CONTD)

REQUIREMENT	DESIGN	COMMENTS
• MEASUREMENT ORIENTATION		
- THE ATF MUST PERFORM ASTROMETRIC MEASUREMENTS ABOUT 2 ORTHOGONAL AXES (X AND Y), IN BOTH PLUS AND MINUS DIRECTIONS FOR EACH AXIS	- ROLL RING PROVIDES A TUBE ROTATION RANGE OF ± 180° AND A POSITION SETTING ACCURACY OF ± 2 ARCMIN	- ROLL RING IS PART OF THE VIBRATION ISOLATION/ VERNIER POINTING SYSTEM
• TRACKING PERIODS		
- THE ATF MUST PROVIDE CONTINUOUS TRACKING PERIODS OF 7 TO 25 MINUTES	- DESIRED TRACKING TIMES MET FOR "STRAWMAN" PLANETARY DETECTION TARGET STAR LIST	- BASED ON THE CURRENT AVOIDANCE CRITERIA, CONTINUOUS TRACKING PERIODS UP TO 21 MIN UTES CAN BE OBTAINED FROM THE SPACE STATION

4.4-6 ATF Mission Requirements/Characteristics (Contd)

The selected optical configuration is the largest size that can be packaged in a single shuttle launch. The maximum diameter and total length (F/D) is constrained by the ability to place the vibration isolation system and the two halves of the telescope tube along with the supporting ASE side by side in the STS bay. A focal ratio of F/D=13 is desired since it yields a near optimum optical configuration which minimizes the combined coma and diffraction effects.

The strawman design employs a belt drive for the Ronchi ruling. This may present problems related to a stable long life; however, the unit is on-orbit replaceable. Subsequent efforts will be required to refine the Ronchi ruling drive mechanism and to assess measurement errors introduced by the ruling. The ruling scan rate is variable and will be selected to operate at a frequency where system dynamics motions at the ruling are minimized.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF MISSION REQUIREMENTS/CHARACTERISTICS (CONTD)

REQUIREMENT	DESIGN	COMMENTS
• OPTICAL CONFIGURATION - SINGLE MIRROR SYSTEM - APERTURE $\geq$ 1.25M - F/D = 13	- "STRAWMAN" DESIGN SATISFIES REQUIREMENTS - RONCHI RULING LOCATED AT PRIME FOCUS - POST-FOCAL-PLANE OPTICS DIRECT BEAM TO SIDE OF TUBE	- SELECTED "STRAWMAN" DESIGN IS THE LARGEST SIZE (SINGLE MIRROR) THAT CAN BE PACKAGED IN STS CARGO BAY
• FIELD OF VIEW (FOV) - $\geq$ 10 ARCMIN	- "STRAWMAN" DESIGN PROVIDES 10 ARCMIN USABLE FOV	- ABBERATIONS RESTRICT USEFUL FIELD OF VIEW FOR SINGLE MIRROR SYSTEM. OTHER OPTICAL CONFIGURATIONS MAY PROVIDE A LARGER USEFUL FOV. THE AVAILABILITY OF BRIGHT REFERENCE STARS IS ENHANCED BY A LARGER FOV.
• RONCHI RULING SCAN RATE - 10 TO 100 LINE PAIR/SEC WHICH IS CONTINUOUSLY VARIABLE	- CONTINUOUSLY VARIABLE SPEED BELT DRIVEN UNIT - REDUNDANT MOTOR DRIVES USED - RONCHI RULING ASSEMBLY CAN BE REMOVED AS A UNIT	- THE ATF ANALYSIS OF THE EFFECT OF STABILITY ERRORS ON MEASUREMENT ACCURACY IS CONTINUING

4.4-7 ATF Mission Requirements/Characteristics (Contd)

The SS CPS will provide ≤1 arcmin pointing accuracy and ≤30 arcsec pointing stability. This is inadequate for the ATF. In the strawman ATF design an annular combined Vibration Isolation and Vernier Pointing System is placed between the telescope and the CPS. This Vibration Isolation/Vernier Pointing System will reduce pointing errors to ≤1 arcsec and will provide sufficient isolation to meet the desired image stability requirements in the critical frequency range of 5 to 200 Hz. Current estimates indicate that a stability of .01 arcsec will be required over the entire critical frequency range. The pointing requirements are covered in more detail in section 6.4.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF MISSION REQUIREMENTS/CHARACTERISTICS (CONTD)

REQUIREMENT	DESIGN	COMMENTS
• POINTING ACCURACY		
- ≤ 1.0 ARCSEC	- VIBRATION ISOLATION/VERNIER POINTING SYSTEM PROVIDED TO REDUCE CPS ERRORS	- CPS REQUIREMENT ≤ 1 ARCMIN
• POINTING STABILITY		
- 0.01 ARCSEC (5-200 Hz)	- VIBRATION ISOLATION SYSTEM PROVIDED TO ATTENUATE SS DISTURBANCES IN FREQUENCY RANGE 5 - 200 Hz	- CPS REQUIREMENTS: JITTER ≤ 15 ARCSEC LONG TERM STABILITY ≤ 30 ARCSEC - ATF ANALYSIS OF THE EFFECT OF STABILITY ERRORS ON MEASUREMENT ACCURACY IS CONTINUING

4.5-1 ATF System Requirements/Characteristics

One of the key drivers in the strawman design was program cost. For this reason a basic requirement is to use flight proven designs or H/W designs derived from the SS and other sources to the extent possible. Most of the ATF data handling and pointing and control subsystems H/W use designs derived from the SS. The extent of H/W inheritance is discussed in the various subsystem sections.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF SYSTEM REQUIREMENTS/CHARACTERISTICS

REQUIREMENT	DESIGN	COMMENTS
• ATF GENERAL REQUIREMENTS		
- SURVIVE AND FUNCTION AS REQUIRED DURING THE LAUNCH, SS OPERATIONAL, AND ORBITAL ENVIRONMENTS FOR THE LIFE OF THE MISSION	- "STRAWMAN" CONCEPTUAL DESIGN IS EXPECTED TO SATISFY GENERAL REQUIREMENTS	- MANY SS REQUIREMENTS ARE TBD
- MATE AND FUNCTION WITH THE STS, SS, CPS, AND OTHER SYSTEMS AS REQUIRED FOR DEPLOYMENT, OPERATION, MAINTENANCE, AND RECOVERY		
- PERFORM THE REQUIRED DATA MANAGEMENT, CONTROL, AND POWER CONDITIONING FUNCTIONS		
- SATISFY ASTROMETRIC SCIENCE AND MISSION REQUIREMENTS		
• DESIGN PHILOSOPHY		
- USE FLIGHT PROVEN DESIGNS AND TECHNOLOGY TO THE EXTENT POSSIBLE	- USES EXISTING HARDWARE AND/OR DESIGNS - USES HARDWARE TO BE DEVELOPED BY THE SS	- SELECTED APPROACH MINIMIZES PROGRAM COSTS AND PROVIDES CAPABILITY FOR EARLY DEPLOYMENT ON THE SS

4.5-2 ATF System Requirements/Characteristics (Contd)

A simple, straightforward approach has been taken in the strawman design to satisfy the failure tolerance and fault protection requirements. To satisfy necessary requirements, block redundancy coupled with automatic safing in the event of a potential catastrophic failure was used. Cross-strapping is used only for non-redundant items such as the FPI. (Note the multiple detector arrangement of the instrument design results in a level of redundancy, and furthermore, it can be replaced on-orbit if necessary.) The minimization of cross-strapping significantly reduces system complexity. After a safing event has occurred, the H/W elements are reconfigured by ground command. The overall approach described here results in reduced costs both for the H/W and for operations. This approach is viable for ATF because the measurements are not time critical.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF SYSTEM REQUIREMENTS/CHARACTERISTICS (CONTD)

REQUIREMENT	DESIGN	COMMENTS
• FAILURE TOLERANCE		
- PROVIDE A FAILURE TOLERANT DESIGN	- USES BLOCK REDUNDANT SYSTEM WITH CROSS-STRAPPING OF FPI	- CROSS-STRAPPING USED ONLY ON ELEMENTS WHERE BLOCK REDUNDANCY NOT FEASIBLE TO MINIMIZE SYSTEM COMPLEXITY
- NO SINGLE FAILURE SHALL BE SYSTEM CATASTROPHIC OR PRECLUDE DEPLOYMENT, RECOVERY, OR ON-ORBIT SERVICING	- SELECTED CONSERVATIVE DESIGN APPROACHES THROUGHOUT	
	- RECONFIGURATION OF HARDWARE ELEMENTS BY GROUND COMMAND	
- FAILURES SHALL NOT PROPAGATE TO INTERFACING EQUIPMENT		
• FAULT PROTECTION		
- PROVIDE FAULT PROTECTION FOR SYSTEM CATASTROPHIC FAILURES	- PROVIDES AUTOMATIC APERTURE DOOR CLOSURE FOR VIOLATION OF SUN AVOIDANCE CRITERIA	- DIRECT SUN INTO THE FPI WILL DESTROY UNIT
	- APERTURE DOOR CLOSES AUTOMATICALLY UPON LOSS OF POWER	

4.5-3 ATF System Requirements/Characteristics (Contd)

No safety related issues have been identified for ATF. Since the ATF is mounted in the CPS and the CPS is under SS control, the ATF movements will be constrained by the SS to avoid interference with other experiments and to prevent collision with the SS structure.

The strawman ATF design is compatible with on-orbit assembly and servicing operations. All planned on-orbit replaceable elements are readily accessible; electronics packages are mounted on the forward and aft end of the telescope. Exposed optical elements will be protected by closing the aperture door to prevent contamination during servicing operations.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF SYSTEM REQUIREMENTS/CHARACTERISTICS (CONTD)

REQUIREMENT	DESIGN	COMMENTS
• SAFETY		
- SATISFY STS AND SS SAFETY REQUIREMENTS	- "STRAWMAN" DESIGN IS EXPECTED TO SATISFY REQUIREMENTS	- THE ATF ANTICIPATES NO SAFETY RELATED ISSUES - THE SS SAFETY REQUIREMENTS ARE TBD
• SERVICEABILITY		
- PROVIDE CAPABILITY FOR ON-ORBIT REPLACEMENT OF ACTIVE ELEMENTS	- USE STANDARD DESIGNS, OPERATIONS, AND TOOLS FOR REPLACEMENT ELEMENTS	- OPTICS WILL BE COVERED DURING SERVICING OPERATIONS
- DESIGNS TO BE COMPATIBLE WITH SS SERVICING AND HUMAN ENGINEERING REQUIREMENTS	- PASSIVE ELEMENTS OF ATF ARE TOUGHENED	
• DEPLOYMENT/RECOVERY		
- DESIGNS TO BE COMPATIBLE WITH ON-ORBIT ASSEMBLY AND SUBSEQUENT DIS-ASSEMBLY OPERATIONS	- "STRAWMAN" CONCEPTUAL DESIGN IS EXPECTED TO SATISFY REQUIREMENTS	- THE ATF WILL PERFORM DESIGN VERIFICATION TESTS IN NEUTRAL BUOYANCY FACILITY - MANY SS REQUIREMENTS ARE TBD

4.5-4 ATF System Requirements/Characteristics (Contd)

The ATF is sensitive to contamination which could significantly degrade the optical throughput or cause asymmetries in optical coatings. Degradation in optical throughput could increase the integration time requirement whereas asymmetries could introduce astrometric measurement errors. As a preventive measure, the primary mirror is maintained above the ambient temperature to prevent condensation.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF STSTEM REQUIREMENTS/CHARACTERISTICS (CONTD)

REQUIREMENT	DESIGN	COMMENTS
• CONTAMINATION		
- THE ATF SHALL CONTROL ITS OUTGASSING AND VENTING PRODUCTS	- ATF MATERIALS ARE SELECTED TO MINIMIZE INTERNAL CONTAMI-NATION	- THE ATF PERFORMANCE AND MISSION SUCCESS ARE SERIOUSLY AFFECTED BY CONTAMINATION
- THE ATF SHALL FUNCTION WITHIN SS CONTAMINATION ENVIRONMENT	- PRIMARY MIRROR HEATED TO PREVENT CONDENSATION - APERTURE DOOR PROVIDES PROTECTION AGAINST CON-TAMINATION SOURCES	- THE SS CONTAMINATION ENVIRONMENT IS TBD; ATF CAN FUNCTION WITHIN CURRENT ESTIMATES
• EMC		
- INTERNAL (HABITABLE-VOLUMES) ELECTRIC AND MAGNETIC FIELDS TO SATISFY MIL-STD-461B	- "STRAWMAN" DESIGN IS EXPECTED TO SATISFY REQUIREMENTS	- THE SS REQUIREMENTS ARE IN THE PROCESS OF DEFINITION
- EXTERNAL ELECTRIC & MAGNETIC FIELDS TO SATISFY GSFC SCIENCE REQUIREMENT	- STRAWMAN DESIGN CAN OPERATE WITHIN EMC ENVIRONMENT PRESENTLY DEFINED FOR SS	- THE GSFC SCIENCE REQUIRE-MENTS ARE MORE STRINGENT THAN MIL-STD-461
- SINGLE-POINT GROUND		

4.5-5 ATF System Requirements/Characteristics (Contd)

The ATF optical alignment requirements at the prime focus (Ronchi ruling) and secondary focus (FPI) are stringent. To satisfy these requirements, on-orbit adjustments can be made to the primary mirror and post-focal-plane optics. The adjustments are made via ground generated commands.

A combined vibration isolation/vernier pointing/roll angle adjustment system is used to couple the telescope to the CPS. This will provide 45-65 dB of vibration isolation between the SS and telescope, and fine pointing control to meet the ATF pointing accuracy and stability requirements.

The ATF telescope will be CG mounted to the CPS to within ±1 cm. Balance weights will be used to meet this requirement.

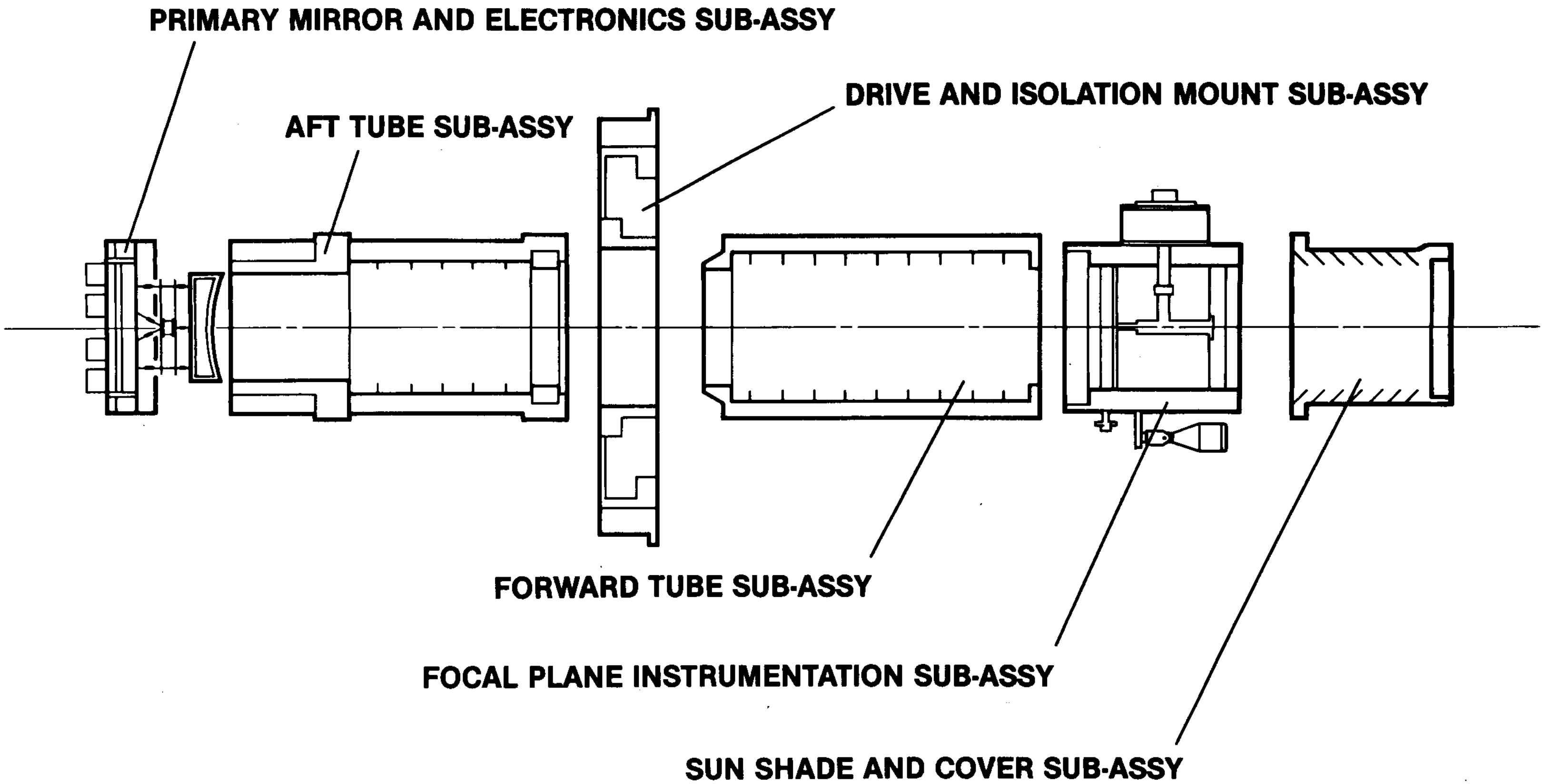
MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF SYSTEM REQUIREMENTS/CHARACTERISTICS (CONTD)

REQUIREMENT	DESIGN	COMMENTS
• ALIGNMENT		
- PROVIDE FOCUS, TILT, CENTERING FOR PRIMARY MIRROR (FIVE DEGREES OF FREEDOM)	- PROVIDE ADJUSTABLE MOUNT FOR PRIMARY MIRROR	- ADJUSTMENTS MADE ON-ORBIT DURING NONOBSERVING PERIODS
- PROVIDE FOCUS FOR FPI	- PROVIDE FOCUS ADJUSTMENT FOR FPI	
• DYNAMICS		
- PROVIDE VIBRATION ISOLATION AS NEEDED TO SATISFY IMAGE STABILITY REQUIREMENTS	- USE COMBINED VIBRATION ISOLATION, VERNIER POINTING, AND ROLL ASSEMBLY TO COUPLE TELESCOPE TO SS CPS	- SS DYNAMICS DISTURBANCES NOT WELL DEFINED - THE ATF ANALYSIS OF THE EFFECT OF STABILITY ERROR ON MEASUREMENT ACCURACY IS CONTINUING
• BALANCE		
- MOUNT TELESCOPE TO ±1 cm OF CG	- ADD BALANCE WEIGHT DURING FINAL SYSTEM INTEGRATION - USE MOVABLE TRIM WEIGHTS FOR FINE ON-ORBIT ADJUSTMENT	

4.6 ATF Subassemblies

The ATF strawman design consists of six subassemblies to facilitate H/W fabrication, system integration, and on-orbit assembly. Prior to launch the primary mirror/electronics subassembly and aft tube subassembly are assembled as a unit. Similarly the forward tube subassembly, Focal Plane Instrumentation subassembly, and sun shade and cover subassembly are assembled as a unit. The final assembly of the two telescope-tube halves to the vibration isolation mount subassembly is made on-orbit.

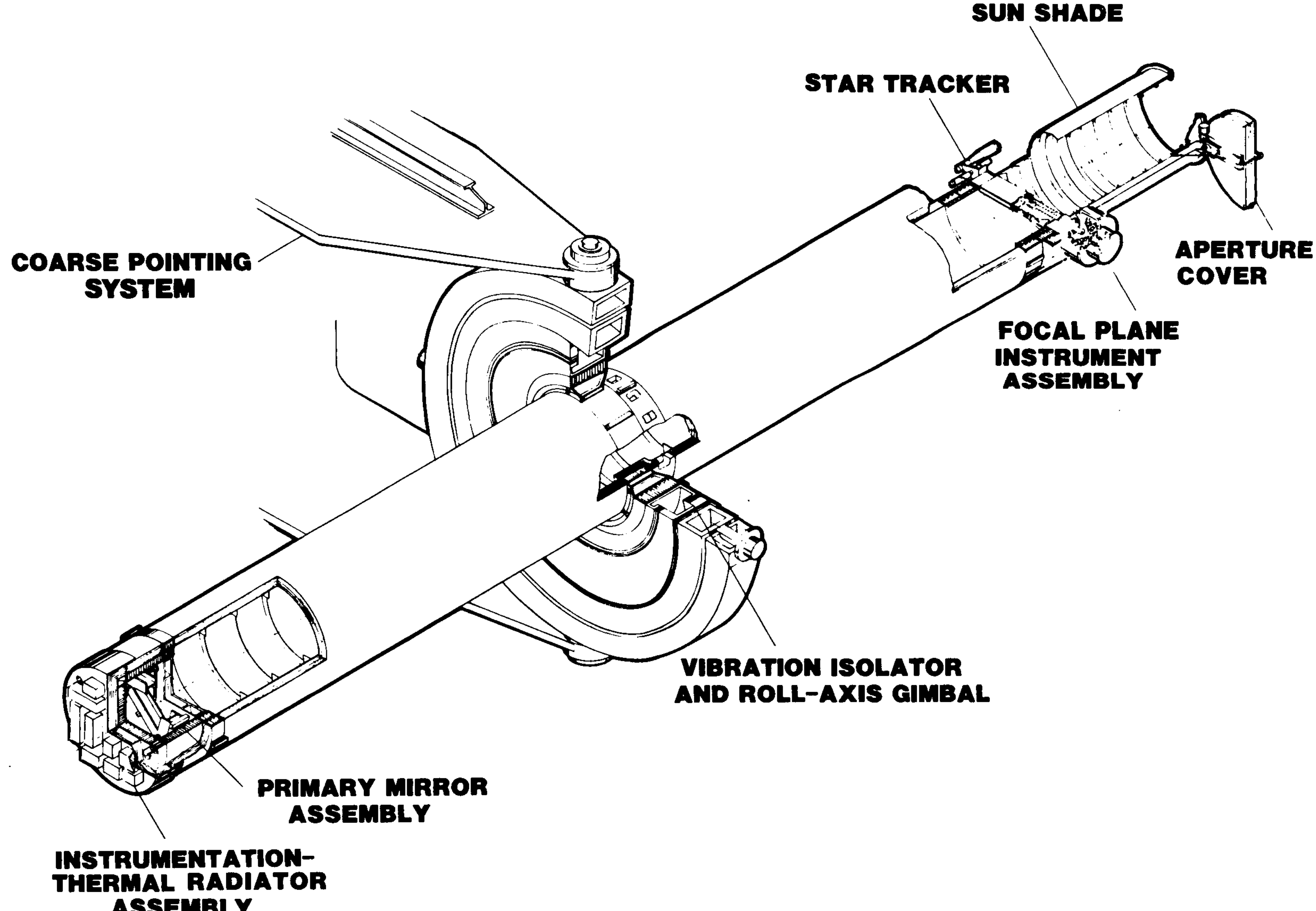
MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF SUBASSEMBLIES



4.7 Pointing

4.7.1 ATF/CPS Mounting Interface Concept. - This figure shows the assembled telescope attached to the SS provided CPS. The aperture door is open and the telescope is in its observing configuration.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF/CPS MOUNTING INTERFACE CONCEPT



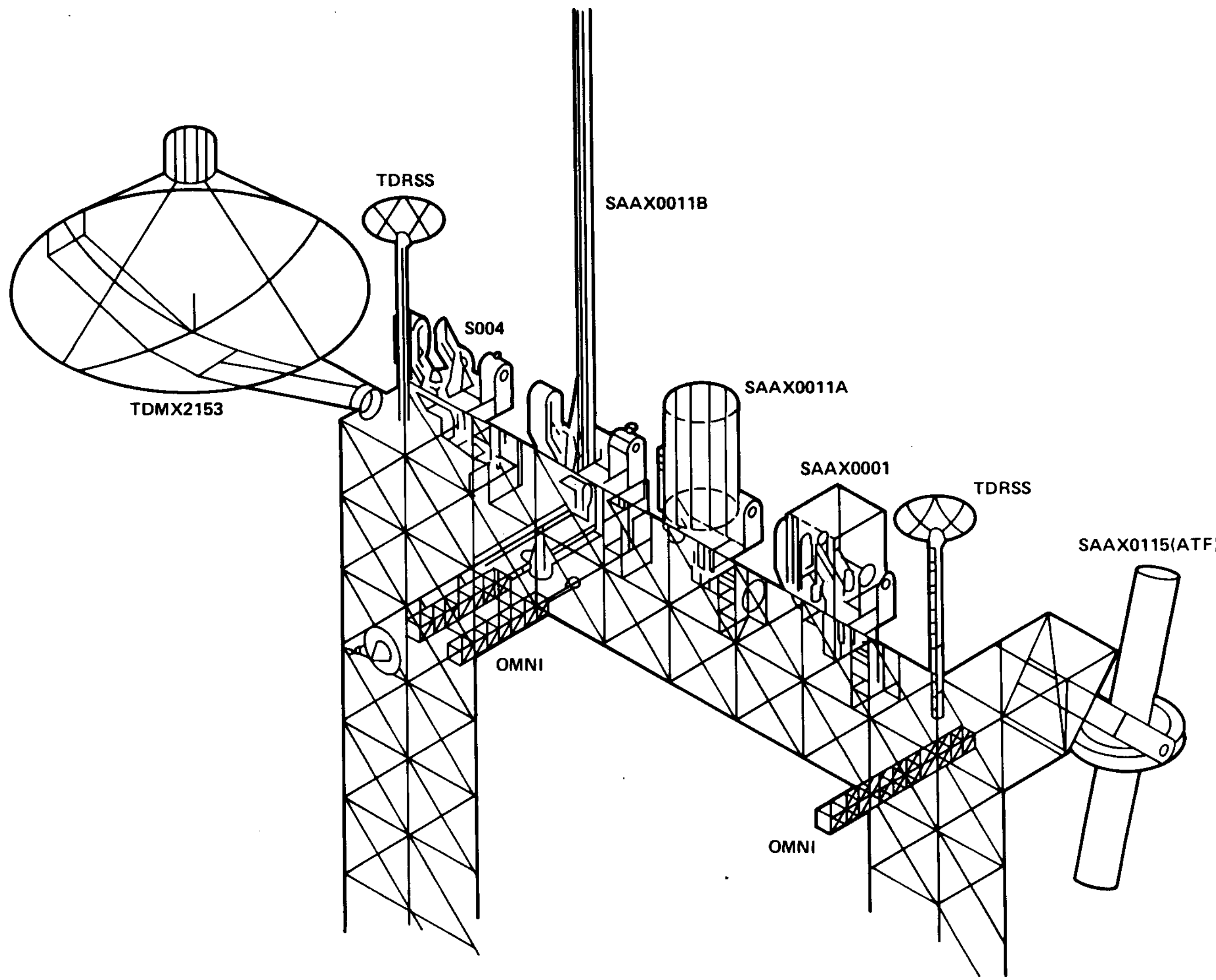
4.7.2 Mounting of ATF on SS. - The current ATF conceptual design and cost estimates are based on the use of a SS-supplied CPS. Neither the SS nor the CPS designs have been firmed up. A variety of CPS mount designs, SS configurations, ATF configurations, and mounting locations have been investigated. It was found that ATF can be adapted to a variety of options provided that a sufficient CPS diameter, swing and payload mass capability exists and that a sufficient SS clearance envelope is available for ATF to cover its desired field of view. To accommodate the required ATF telescope arc of travel (from zenith to straight aft, north, and south) with a CPS designed with a 4-m hole size and 6-m swing, a truss extension structure must be placed between the SS and CPS. (See next figure for representative configuration.) One of the most favorable mounting arrangements is with one of the major axes of the CPS maintained parallel to the SS-orbit pole and rotated at the rate of 1 rev/orbit. For the SS double keel configuration, a mounting location on the aft north side of the upper science keel has been tentatively reserved for ATF.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
MOUNTING OF ATF ON SPACE STATION

- THE ATF CAN BE ADAPTED TO A VARIETY OF MOUNTING LOCATIONS AND CPS CONFIGURATIONS
- PREFERRED MOUNTING LOCATION DEPENDS ON SELECTED ATF FLIGHT CONFIGURATION (I.E., SIZE, CG LOCATION) AND ON SS CPS CHARACTERISTICS (I.E., SWING, VIEWING RESTRICTIONS)
- CANDIDATE MOUNTING LOCATIONS WHICH HAVE BEEN CONSIDERED ARE:
  - AN AFT EXTENSION ON NORTH END OF UPPER SCIENCE BOOM
    - PREFERRED BY ATF OPTIONS WITH LONG TUBES
    - TENTATIVELY RESERVED FOR ATF
  - NORTH FACING END OF UPPER SCIENCE BOOM
    - PREFERRED FOR POLAR MOUNT
  - TOP OF NORTH SIDE OF UPPER SCIENCE BOOM
    - REQUIRES REAL ESTATE, WILL IMPACT OTHER USERS
- SPACE STATION CPS VARIABLES WHICH AFFECT MOUNTING OPTIONS INCLUDE:
  - ALLOWABLE PAYLOAD SWING LENGTH
  - INTERFERENCE WITH OTHER PAYLOADS
  - DISTURBANCE ENVIRONMENT
  - CPS ARTICULATION DESIGN, ORIENTATION WITH RESPECT TO ORBIT POLE AND GIMBAL LOCK

4.7.3 ATF Mounted on SS (Baseline Design). - This figure shows the ATF mounted to an extension on the aft north side of the SS upper science keel. The CPS is mounted to an inclined face of the extension structure. This arrangement will permit the ATF to look at the zenith, straight aft, north, and south.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF MOUNTED ON SPACE STATION (BASELINE DESIGN)



4.8 Mass Properties

4.8.1-1 Estimated ATF Mass. - The next few charts present a weight breakdown for the strawman ATF. The telescope structural weights were computed from the conceptual design layout drawings. Most of the structure is graphite epoxy with a density of 1.52 gm/cm^3. Focal plane instrument weights were estimated from layout drawings and from a similar existing instrument in use at the Steward Observatory. Primary mirror weights were based on areal density of 125 kg/m^2 which is within current technology. Many of the electronics units are inherited from the SS. For these cases, the SS unit box weight estimates were used. Pointing and control subsystem elements such as the astro star tracker and precision gyros are based on existing H/W. Other elements were estimated based on similarity with existing H/W. The airborne support equipment (supports ATF in STS bay) was estimated to be 25% of the supported system mass. A maximum balance weight requirement was estimated to be 150 kg or about 4% of the telescope tube assembly weight. Based on these assumptions the telescope plus vibration isolation system weighs 5105 kg and the total launch mass is 6420 kg.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ESTIMATED ATF MASS

TELESCOPE STRUCTURE/MECHANISM	kg	
AFT TUBE SUBASSEMBLY STRUCTURE	734	
FORWARD TUBE SUBASSEMBLY STRUCTURE	591	
FORWARD INSTRUMENTATION SUBASSEMBLY STRUCTURE	564	
AFT END MOUNTING STRUCTURE	143	
SUNSHADE/APERTURE DOOR	105	
BAFFLING	100	
THERMAL BLANKETS	50	
FOCAL PLANE INSTRUMENT	200	
IMAGING CAMERA	5	
RONCHI RULING/POST FOCAL OPTICS	31	
PRIMARY MIRROR	152	
PRIMARY MIRROR SUPPORT/CONTROL SYSTEM	100	
SUBTOTAL		2775
BALANCE WEIGHT	150	
TOTAL		2925

__4.8.1-2 Estimated ATF Mass (Contd)__. - **(See text for figure 4.8.1-1.)**

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ESTIMATED ATF MASS (CONTD)

TELESCOPE MOUNTED ELECTRONICS

	kg	
• COMMAND AND DATA HANDLING		
AFT NETWORK INTERFACE UNITS (NIU) (2)	28	
AFT STANDARD DATA PROCESSORS (SDP) (2)	46	
AFT MULTIPLEXER/DEMULTIPLEXER (MDM) (2)	20	
FORWARD MULTIPLEXER/DEMULTIPLEXER (MDM) (4)	60	
AFT SIGNAL CONDITIONING UNIT (SCU) (2)	14	
FORWARD SIGNAL CONDITIONING UNIT (SCU) (2)	14	
• POINTING AND CONTROL		
SUN SENSOR (4)	4	
STAR TRACKER (2)	100	
PRECISION GYRO (1)	17	
AFT STANDARD DATA PROCESSORS (SDP) (2)	46	
• POWER		
AFT POWER INTERFACE UNIT (PIU) (2)	16	
CABLING (HALF FORWARD AND HALF AFT)	50	
SUBTOTAL AFT	195	
SUBTOTAL FORWARD	220	
TOTAL		415

4.8.1-3 Estimated ATF Mass (Contd). - (See text for figure 4.8.1-1.)

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ESTIMATED ATF MASS (CONTD)

	kg	
<u>VIBRATION ISOLATION ASSEMBLY</u>		
RING ASSEMBLY WITH VERNIER POINTING AND ROLL RING	1735	
CONTROL ELECTRONICS	30	
TOTAL		1765
TOTAL TELESCOPE SYSTEM		5105
<u>INTERNAL CONTROL CONSOLE</u>		
RACK MOUNTED MODULES (2)	40	
TOTAL		40
<u>AIRBORNE SUPPORT EQUIPMENT (ASE)</u>		
TELESCOPE TUBE CRADLE	835	
VIBRATION ISOLATION SYSTEM CRADLE	440	
TOTAL		1275
LAUNCH MASS		6420

4.8.2 ATF Inertial Properties. - The mass properties of the ATF are summarized on this chart. As described earlier, the telescope is attached to the station CPS at its (telescope) CG. For the strawman configuration, the yoke on the CPS would have to be about 11.1 m (this distance includes accommodation of the electronics on the end of the tube while the value on the following chart of 10.59 is referenced to the end of the tube) to accommodate swingthrough of the telescope. Note: the strawman mission design and assumed mounting location does not require swingthrough.

The analysis of the CG location in the STS bay indicates that a considerable margin exists between the ATF CG location and the cargo-bay CG constraints. The ATF CG without consideration of the effects of the SS docking adapter is about 0.6 m inside the aft boundary of specified STS limits. The docking adapter would tend to provide more margin.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF INERTIA PROPERTIES

- TELESCOPE SYSTEM AS MOUNTED IN CPS
  - MOUNTED TO CPS AT CG (BALANCE WEIGHT ADDED AS REQUIRED)
  - CG LOCATION - 10.59 m FROM AFT END OF TELESCOPE TUBE
  - INERTIA PROPERTIES ABOUT CG IN DEPLOYED CONFIGURATION

    $I_{pitch} = I_{yaw} = 160{,}000\ kg{\cdot}m^2$

    $I_{roll} = 19{,}300\ kg{\cdot}m^2$

- TELESCOPE SYSTEM AS MOUNTED IN STS
  - DIVIDED INTO THREE MAJOR ASSEMBLIES
  - PACKAGE SIZE 4.4 m DIA x 13.6 m LONG
  - ASSUMED TO BE LOADED IN AFT PORTION OF STS CARGO BAY
  - INERTIA PROPERTIES IN LAUNCH CONFIGURATION

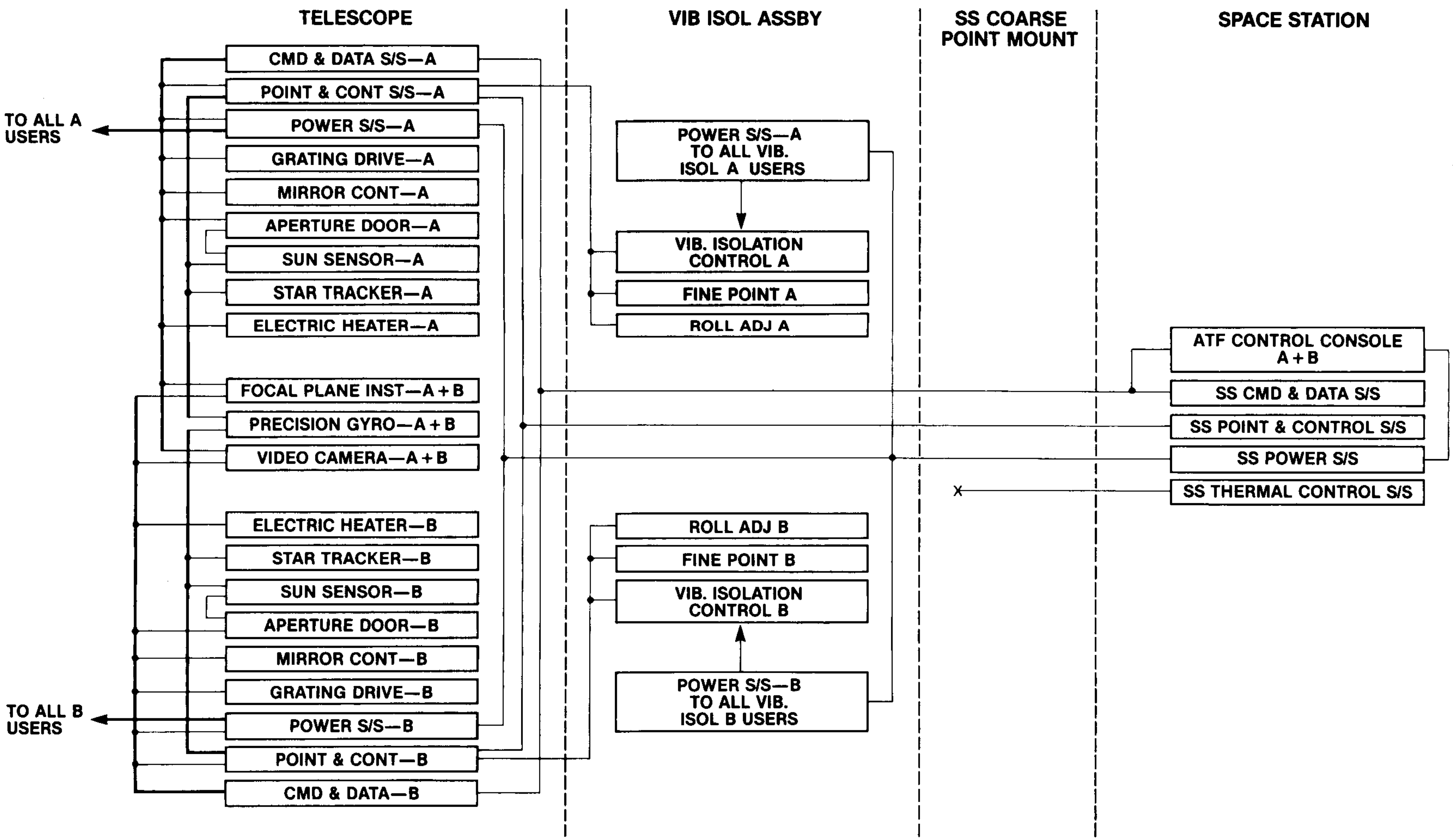
    $CG_z = CG_y \approx$ PAYLOAD BAY CENTERLINE

    $CG_x = 4.78$ m FROM AFT OF CARGO BAY

4.9 ATF Block Diagram

This figure presents a top-level block diagram which illustrates the redundancy approach used for ATF and the interfaces between the various elements. Most of the units of the ATF are block redundant as can be seen from the string A and string B elements on the figure. Only in the case of the FPI (plus imaging camera) and precision gyro which has built in redundancy, were units cross-strapped. The vibration isolation system will be block redundant to the extent possible (it may not be possible to duplicate actuators or magnetic windings). Since the ATF electronics are mounted on the telescope or vibration isolation assembly, very few power or signal lines are required to cross the CPS. Current estimates indicate that active cooling is not required by the ATF so the SS active cooling line is shown blocked off. There exists some uncertainty about the power dissipation capabilities of the vibration isolation system, some active cooling may be required after the system is more clearly defined.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF BLOCK DIAGRAM



4.10-1 ATF Operational Power Requirements

The following charts list the estimated power requirements for the ATF. Both the average power used over one orbit and the peak power used at some point during an orbit are shown. Space Station estimates were used for power levels for SS-derived electronics boxes. Off-the-shelf H/W power estimates were taken from literature. The remaining elements were estimated based on similarity with existing flight- or ground-based H/W. The total estimated average power level is 1408 W and peak loads are 2503 W.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF OPERATIONAL POWER REQUIREMENTS

ITEM	POWER REQUIRED (W)	
	AVG	PEAK
COMMAND AND DATA		
NETWORK INTERFACE UNIT	60	60
STANDARD DATA PROCESSOR	100	100
MULTIPLEXER/DEMULTIPLEXER	97	97
SIGNAL CONDITIONING UNIT	40	40
POINTING AND CONTROL		
SUN SENSORS	10	10
STAR TRACKER	80	80
PRECISION GYRO	30	30
STANDARD DATA PROCESSOR	100	100
ROLL ADJUSTMENT DRIVE/CONTROLLER	20	220
FINE POINTING/VIBRATION ISOLATION SYSTEM	420	840

4.10-2 ATF Operational Power Requirements (Contd)

(See text for figure 4.10-1.)

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENT
ATF OPERATIONAL POWER REQUIREMENTS (CONTD)

ITEM	POWER REQUIRED (W) AVG	PEAK
POWER		
TELESCOPE POWER INTERFACE UNIT	100	100
FPI	100	500
IMAGING CAMERA	SMALL	30
MIRROR HEATER	96	96
MIRROR CONTROL SYSTEM	SMALL	40
RONCHI RULING DRIVE	50	50
APERTURE DOOR	5	10
CONTROL CONSOLE	100	100
TOTAL POWER REQUIRED	1408	2503

4.11 ATF Environments Considerations

Techniques to minimize the sensitivity of the ATF to external environments have been examined. In the case of contamination, the preventive measures shown on the chart were taken. Other measures have been suggested such as high-voltage electrostatic retardation devices. These options will be considered in future studies when the SS environments are better defined.

Image stability is of major importance to ATF so the SS dynamics environment is of prime concern. To minimize dynamic disturbances at the Ronchi ruling, a vibration isolation system has been selected for the strawman design. A similar program being conducted by DOD, the Space Active Vibration Isolation (SAVI) program, indicates that the ATF requirement should be readily achievable.

The radiation dose of approximately 5000 rads (through 1 gm/cm^2 spherical shield) over a 20-yr mission and a peak dose rate of 10^{-2} to 10^{-3} rads/sec while traversing the South Atlantic Anomaly (SAA) or from large solar flares are not expected to pose serious problems for the ATF. Electronics designs should present no problem. The most sensitive items are the optics and detectors in the vicinity of the FPI. Substantial inherent shielding (>1 gm/cm^2) exists for these items from the telescope tube and supporting structure. Some tests will be required during the H/W program to verify radiation performance of the optical elements. Additional shielding can be added if required.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ATF ENVIRONMENTS CONSIDERATIONS

- PRIMARY ENVIRONMENTS OF CONCERN ARE CONTAMINATION, DYNAMICS, AND RADIATION
- CONTAMINATION
  - HEAT MIRROR TO MINIMIZE CONDENSATION
  - CLOSE APERTURE DOOR DURING PERIODS OF HIGH CONTAMINATION
  - CONTROL VIEWING DIRECTION TO AVOID ATOMIC OXYGEN, FORWARD, AND RETURN CONTAMINATION FLUXES
- DYNAMICS
  - MOUNT CRITICAL OPTICAL ELEMENTS IN RIGID SUPPORTS
  - ATTENUATE DISTURBANCES TO ACCEPTABLE LEVELS VIA VIBRATION ISOLATION/VERNIER POINTING SYSTEM (CRITICAL FREQUENCY RANGE IS 5 TO 200 Hz)
- RADIATION
  - TOTAL RADIATION DOSES RANGE FROM 130 TO 260 RADS/YR WITHIN A SPHERICAL SHIELD OF 1 g/cm
  - ALL SENSITIVE OPTICS ENCLOSED SO INHERENTLY SHIELDED FROM EXTERNAL SOURCES
  - DOSE LEVELS ARE BELOW DAMAGE THRESHOLDS FOR MOST OPTICAL GLASSES
  - THE PMT DETECTOR IS SHIELDED TO MINIMIZE RADIATION INDUCED CURRENTS
  - FIBER OPTICS PERFORMANCE NEEDS TO BE ESTABLISHED

4.12 On-Orbit Assembly/Operations

This chart describes the on-orbit assembly operations required by the ATF. The use of the SS payload servicing bay is assumed in the baseline assembly scenario. However if the service bay does not exist when the ATF is deployed, the ATF can be assembled directly onto the CPS. The major advantage to the service bay is that it should provide some additional protection from contamination.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
ON-ORBIT ASSEMBLY/OPERATIONS

- ATF DIVIDED INTO THREE MAJOR ASSEMBLIES FOR LAUNCH
- ATF ASSEMBLED IN SS SERVICE BAY TO MINIMIZE CONTAMINATION
- ATF ON ORBIT ASSEMBLY SCENARIO
  - INSTALL CONTROL CONSOLE IN PRESSURIZED MODULE
  - EXTRACT AFT SECTION OF ATF FROM STS AND TRANSPORT TO SERVICE BAY
  - EXTRACT VIBRATION ISOLATION ASSEMBLY FROM STS AND TRANSPORT TO SERVICE BAY
  - EXTRACT FORWARD SECTION OF ATF FROM STS AND TRANSPORT TO SERVICE BAY
  - REMOVE PROTECTIVE COVER FROM AFT SECTION AND ASSEMBLE TO VIBRATION ISOLATION SYSTEM
  - REMOVE PROTECTIVE COVER FROM FORWARD SECTION AND ASSEMBLE TO REMAINDER OF ATF
  - REMOVE PROTECTIVE COVER AND INSTALL RONCHI RULING
  - PERFORM POST ASSEMBLY INSPECTION/CHECKOUT IN SERVICE BAY
  - TRANSPORT ASSEMBLED ATF FROM SERVICE BAY TO CPS
  - INSTALL ATF IN SS CPS AND MATE CONNECTORS
  - PERFORM DETAILED CHECK OF ATF AND POINTING SYSTEM
- DISASSEMBLY FOR RETURN TO EARTH USES SERVICE BAY
- ON-ORBIT SERVICING PERFORMED WITH ATF MOUNTED IN CPS

4.13 System Trade Issues/Open Areas

This chart lists the major trades/open issues that have been identified that are classified as system level items. Many other trades/open issues have been identified at the subsystem level and will be covered therein.

Optical configuration is a very important trade item. Alternate configurations which employ larger primary mirrors and folded optics appear attractive and are being or will be examined in depth. This option could eliminate the need for on-orbit assembly and may require only half the current tube length, but will require an increased tube diameter.

A variety of trades/open issues could come forth after the SS and CPS designs become firmed up. Efforts will be required to follow design activities and to define requirements. Definition of contamination environments and methods to accommodate these environments are a particularly important topic.

Additional efforts are required in the general area of error analyses. More complete dynamic system simulations are required which couple in the effects of pointing errors and the systems used to control and suppress these errors.

MISSION AND SYSTEM DESCRIPTION AND REQUIREMENTS
SYSTEM TRADE ISSUES/OPEN AREAS

- ALTERNATE OPTICAL CONFIGURATION
  - FOLDED OPTICS AND OTHER OPTIONS
- DEFINITION OF SS ENVIRONMENTS
  - CONTAMINATION
  - DISTURBANCE
- DEFINITION OF SS POINTING MOUNT SYSTEM
  - CONFIGURATION
  - DETERMINATION OF OPTIMUM MOUNTING LOCATION
- EXAMINATION OF CONTAMINATION RETARDATION TECHNIQUES
  - USE OF HIGH-VOLTAGE RETARDATION
- DETAILED ERROR ANALYSIS FOR ATF
  - POINTING STABILITY
  - VIBRATION ISOLATION/VERNIER POINTING SYSTEM

5.0 OPTICS AND FOCAL PLANE INSTRUMENT DESCRIPTION AND REQUIREMENTS

5.1-1 Primary Mirror

The basic design of the primary mirror is determined by optimizing performance while considering the need to maximize photon collecting area to defeat photon statistics errors, to diminish the spatial extent of the diffraction pattern, and to minimize errors induced by comatic abberration. Preliminary analyses indicate that the optimal measurement accuracy is achieved when the geometric diffraction and coma images are approximately the same size; this occurs in the vicinity of F/D 13 to 14. With a focal ratio in this range, the largest size that can be packaged in the STS bay is a telescope with a 1.25-m primary mirror.

OPTICAL SUBSYSTEM — PRIMARY MIRROR

REQUIREMENT	COMMENTS
• DIAMETER - 1.25 m	- CONSTRAINED BY STS BAY DIMENSIONS - DRIVEN BY NEED FOR PHOTONS, PHOTON RATE INCREASES AS D^2
• FOCAL LENGTH - 16.25 m	- CONSTRAINED BY STS BAY DIMENSIONS - DRIVEN BY NEED FOR HIGH F/NUMBER TO REDUCE COMA
• FIELD OF VIEW - 10 ARCMIN DIA	- CONSTRAINED BY COMA - DRIVEN BY NEED TO OBTAIN SUFFICIENT REFERENCE STARS IN THE FOV
• MIRROR FIGURE - ON AXIS PARABOLOID - SURFACE QUALITY 1/20 WAVELENGTH ON A SCALE OF 5 cm - TEMPORAL STABILITY OF OPTICAL FIGURE: TBD - OTHER REQUIREMENTS: TBD	- FIGURE AND TEST AT SAME TEMPERATURE AS FINAL USE WITH ALLOWANCE FOR GRAVITATIONAL DEFORMATION DURING TESTING - SPECIFIC ADDITIONAL TOLERANCES ON DEPARTURES FROM CYLINDRICAL SYMMETRY TO BE SPECIFIED
• MIRROR MATERIAL - ULTRA LOW EXPANSION GLASS - CTE AT OPERATING TEMP $<10^{-8}$ /DEG C - MASS < 200 kg	- CROSSOVER TEMPERATURE OF CTE CURVE TUNED TO DESIRED OPERATING TEMPERATURE - MIRROR LIGHTENED WITH CUSTOMARY HOLLOWS OR RIBBING

5.1-2 Primary Mirror (Contd)

The reflective primary mirror will be overcoated by two masks, one for apodization and the other to mask the shadow cast by the Ronchi ruling assembly.

The shadow cast by the Ronchi ruling assembly falls on different parts of the primary mirror for different stars. An ATF design principle is to minimize the degree to which different stars illuminate differing optical surfaces. Therefore, the Ronchi ruling assembly shadow mask (a central rectangular strip) will eliminate reflections from areas of the primary mirror which are not illuminated identically by all stars in the field. This will tend to minimize systematic errors.

Because the combination of diffraction and asymmetric comatic abberrations poses one of the major challenges to finding a robust image center for each star, limiting the diffractive spread of light is important to optimizing the performance of the system. The diffractive spread of the light can be significantly reduced by darkening the edge of the primary mirror by a process called apodization. This will result in smaller image sizes permitting ruling width to be reduced and enhancing ATF efficiency.

OPTICAL SUBSYSTEM — PRIMARY MIRROR (CONTD)

REQUIREMENT	COMMENTS
• MIRROR MASKINGS - SHADOW MASK: APPROXIMATELY 10 cm WIDER THAN THE RONCHI RULING ASSEMBLY	- A BAR SHAPED MASK WILL BE PLACED ON THE PRIMARY MIRROR UNDER THE RONCHI RULING ASSEMBLY
- APODIZATION RING: APODIZATION FUNCTION TBD	- AN APODIZATION RING ON THE PRIMARY MIRROR WILL OBSCURE 100% OF THE LIGHT AT THE OUTER EDGE AND WILL FADE TO FULL REFLECTIVITY TOWARD THE CENTER APPROXIMATELY 25% OF THE LIGHT WILL BE LOST BY THIS APODIZATION.
• COATINGS - REFLECTIVE COATINGS: ALUMINUM PLUS OVERCOATING - NONREFLECTIVE MATERIAL FOR APODIZATION RING AND MASK	– REFLECTIVITY MAXIMIZED BETWEEN 4000 AND 8000 Å.
• TEMPORAL STABILITY OF REFLECTIVITY - ± 0.3% PER QUADRANT OF SURFACE WITH ALL POSSIBLE QUARTERING BOUNDARIES	
• MIRROR MOUNT - KINEMATIC WITH THREE DEGREES OF TRANSLATIONAL FREEDOM AND TWO TILT AXES WITH CAGING FOR LAUNCH	- FOCUSING PERFORMED AT INITIAL OPERATION, THEN PERIODICALLY BETWEEN OBSERVATIONS

5.2-1 Ronchi Ruling

The purpose of the Ronchi ruling is to provide basic experiment metric information by modulating starlight while being translated across the star field image in the focal plane. The present system H/W approach is aimed entirely at obtaining positional measurements at the desired measurement accuracy without reliance on extensive modeling to remove systematic errors. This approach drives substantive aspects of the design, most notably the Ronchi ruling constant. The baseline Ronchi ruling constant of about 10 line pairs/mm and the unequal line spacing was determined on the basis of requiring that the amount of light from a single image falling from one ruling clear space to the next not be so large as to corrupt the instrument response function's relationship to an image's true centroid and by the requirement to keep the clear space sufficiently narrow as to maximize the statistical value of each collected photon.

The ruling should be as long as possible so that errors can be averaged over a large number of lines; the selected length (600 mm) is the longest that can be packaged in the telescope tube. The fabrication techniques for the ruling should be chosen to avoid sharp discontinuities in line spacing and phase and to avoid having periodic errors or defects repeated in the same place in every line.

OPTICAL SUBSYSTEM — RONCHI RULING

REQUIREMENT	COMMENTS
• RULING TYPE - TRANSMISSION RULING WITH ALTERNATING OPAQUE AND TRANSPARENT LINES OF UNEQUAL WIDTH	
• RULING CONSTANT - APPROXIMATELY 10 LINE PAIR/mm - MODIFIED SPACING: 0.3 ARCSEC CLEAR SPACE ($\approx$ 55 μ) 0.9 ARCSEC OPAQUE SPACE ($\approx$ 165 μ)	- THE 0.3 ARCSEC CORRESPONDS TO A RULING LINE CLEAR SPACE SIZED TO THE DIFFRACTION AIRY DISC IN RED LIGHT (8000 Å).
• ACTIVE AREA - 48- BY 600-mm - 6000 MODIFIED UNEVEN LINE PAIRS OVER ACTIVE LENGTH • LINE DIRECTION - PERPENDICULAR TO LENGTH	- A CLEAR SPACE (NO LINES) 48- BY 48-mm SQUARE AT ONE END IS REQUIRED TO ALLOW UNOBSTRUCTED VIEWING OF STAR FIELDS WHEN NECESSARY AND TO DETERMINE STAR SEPARATION FOR ASSESSING INTEGRAL NUMBER OF LINE SPACINGS.
• DIMENSIONAL ARRAY - RULING ACCURACY TO 0.05 μ IN EACH LINE - OTHER SPECIFICATIONS TBD	- RULING ACCURACY BETTER THAN APPARANT VARIATIONS INDUCED BY GUIDING SO THAT DATA CAN BE RECTIFIED BY TIME FOLDING WITH RESPECT TO MODULATIONS OF THE TARGET STAR.

5.2-2 Ronchi Ruling (Contd)

All the stars must see the same effective ruling modulation. Thus the scale and the alignment of the ruling must remain constant to within a small fraction of the measurement accuracy (to approximately 1 μarcsec) for at least one FOV crossing time (<2 min) on a spatial scale substantially larger than the FOV (≈100 mm). Variations on larger and slower scales affect all the stars equally and thus can be accounted for in the analyses. Several factors can change the projected scale (ruling constant) and alignment of the ruling: spatial or temporal nonuniformities of temperature, coefficient of thermal expansion (CTE), and the angular disturbances of pitch* and yaw*. To satisfy the above requirements, tolerances of 1 part in 600 million must be applied to each error source on the relevant time and spatial scales.

To obtain measurements of the perturbations in relative star positions along some arbitrary axis in space, measurements in X and Y directions must be made.

The ruling must be kept perpendicular to the optical axis so that focus can be maintained while the ruling traverses the field of view.

* Defined in 5.2-3

OPTICAL SUBSYSTEM — RONCHI RULING (CONTD)

REQUIREMENTS	COMMENTS
• SUBSTRATE - MATERIAL: TBD - CTE AT OPERATING TEMP < 10^{-8} /°C - SPATIAL UNIFORMITY OF CTE: $\pm 10^{-8}$ VARIATIONS OVER 100 mm - SPATIAL UNIFORMITY OF THERMAL EXPANSION: 1 PART IN 6 X 10^{8} ON A SPATIAL SCALE OF 100 mm AND ON A TIME SCALE OF 2 MIN	- SPATIAL UNIFORMITY OF THERMAL EXPANSION DEFINED AS ΔT x CTE.
• COVER GLASS - MATERIAL: SAME MATERIAL AND TOLERANCES AS SUBSTRATE - METHOD OF ATTACHMENT TO SUBSTRATE: TBD	
• MEASUREMENT AXIS - ACCURACY BETWEEN X AND Y DIRECTIONS: TBD - STABILITY OF MEASUREMENT AXIS DURING OBSERVATIONS: TBD	
• ALIGNMENT TO OPTICAL AXIS - PERPENDICULAR TO WITHIN TBD	

5.2-3 Ronchi Ruling (Contd)

The line modulation rate or measurement frequency will be selectable between 10 and 100 Hz. To minimize measurement errors, vibrations at or near the measurement frequency, which could induce nonmetric modulations of the star signals, must be controlled. The operating frequency will be selected on-orbit to fall within a dynamically quiet regime to minimize vibrations at the modulation frequency. In addition, the rate must be maintained stable during a traverse to within a small fraction of the guiding errors.

Errors in alignment and ruling motion must be kept within the limits shown on this chart. The alignment angles are defined as follows: Yaw is a rotation about the optical axis in a plane containing the motion vector of the ruling; Roll is rotation about the motion vector; and Pitch is rotation about an axis perpendicular to the plane defined by the motion vector and the optical axis. The need for good imagery (focus) constrains Roll and Pitch errors. The requirements for stability of motion constrain Pitch and Yaw errors.

The requirement to maintain focus (for a defocus blur of less than 1 micron) limits Pitch and Roll to ±1.8 arcmin. The requirements for stability of motion in Pitch and Yaw result in alignment constraints much more stringent and are derived from the tolerances quoted on the previous chart of 1 part in 600 million.

OPTICAL SUBSYSTEM — RONCHI RULING (CONTD)

REQUIREMENTS	COMMENTS
• LINE MODULATION RATES - 10 TO 100 LINE PAIR/SEC - MOTION REVERSIBLE IN THE DATA TAKING MODE	
• LINEAR MOTION RATES - 1 TO 10 mm/SEC	
• MOTION RATE ADJUSTABILITY - ±0.01 % (LOGICAL RESOLUTION)	
• MOTION RATE STABILITY DURING A TRAVERSE - ±0.01 % OUTSIDE OF CRITICAL FREQUENCY RANGE - ±TBD WITHIN CRITICAL FREQUENCY RANGE	- THE CRITICAL FREQUENCY RANGE IS 5 TO 200 Hz
• STABILITY OF RULING MOTION - ROLL: ±1.8 ARCMIN - PITCH: ±12 ARCSEC ON A SCALE OF 100 mm - YAW: ±12 ARCSEC ON A SCALE OF 100 mm - MINIMUM RADIUS OF CURVATURE OF BENDS IN RULING WAYS: 1.7 km	
• TESTING - PARAMETERS TO BE VERIFIED ON THE BASIS OF LINE AVERAGING OVER THE ACTIVE WIDTH OF THE RULING	

5.3 Relay Optics

Once the light has passed through the ruling, the metric information has been encoded into time information and the instrument performance is no longer critically dependent on angle of the light path. The function of the relay optics is to transfer the ruling modulated light to the FPI image plane outside the telescope tube and to increase the plate scale. The relay optics consist of a diagonal mirror, and a multielement relay lens. The relay optics are still capable of generating systematic errors through nonuniform absorption of light because the light beyond the ruling contains information about position within the image and on the primary mirror. Thus the specifications for the radiation hardness and the uniformity of transmission or reflection of light will be stringent.

The diagonal mirror will need to be constructed of a material with a low coefficient of thermal expansion to minimize the amount of thermal distortion that can occur as the temperature changes. The relay optics are housed to block direct influx of contaminants. This sealed assembly also reduces the ruling exposure to contaminants, except for its face exposed to the primary mirror.

OPTICAL SUBSYSTEM — RELAY OPTICS

REQUIREMENTS	COMMENTS
• RELAY LENS	
- OBJECT FIELD: F/13 FLAT REAL IMAGE 48 mm DIAMETER - MAGNIFICATION RATIO: 2.5 - ABERRATION SPECIFICATIONS: TBD - OBJECT TO IMAGE DISTANCE: 980 mm - TRANSMISSIVITY: >80% IN SPECTRAL RANGE 4000 TO 8000 Å - COLOR CORRECTION RANGE: 4000 TO 8000 Å	- OBJECT FIELD LOCATED AT RONCHI RULING. MIRROR PLACED BETWEEN OBJECT FIELD AND RELAY LENS. - LEVER ARMS FOR RELAY LENS ADJUSTED TO PROVIDE A 2.5 TIMES INCREASE IN PLATE SCALE. - RELAY OPTICS HOUSED IN SEALED STRUCTURAL ASSEMBLY TO PREVENT CONTAMINATION.
• FOCUSING OF OBJECT FIELD AT FOCAL PLANE INSTRUMENT	
- RELATIVE MOTION OF RELAY LENS ELEMENTS WITH NO CHANGE TO MAGNIFICATION RATIO	- MOVEMENT OF THE FOCAL PLANE INSTRUMENT IS AN ALTERNATIVE FOCUSING TECHNIQUE.
• DIAGONAL MIRROR	
- FLATNESS: TBD - MATERIAL ULTRA-LOW-EXPANSION GLASS - COATING: ALUMINUM PLUS OVERCOATING	- MIRROR PLACED AT 45° INCLINATION TO OPTICAL AXIS - MIRROR SIZED TO PRODUCE NO VIGNETTING OF 48-mm FOV AT F/13.

5.4-1 Focal Plane Instrument

The FPI consists of light pickups, fiber optics, detectors, a visible imager, light pickup arm mechanisms, and electronics. The light pickup assemblies are positioned over the target and reference frame stars in each field to be investigated. These light pickups are S/W configurable to allow study of many star fields and to permit variations in the investigation program to occur after launch. The strawman design uses 32 individually positionable, actuator-driven pickup arms. Each arm is equipped with an iris, a Fabry lens, and a mirror to focus and divert the light to the optical fiber face. The optical fiber carries the light to a dichroic mirror and collimating lens which directs the light to red and blue light sensitive photodetector devices. The basic design of the FPI is similar to the MX spectrometer that has been in use at the Steward Observatory since 1984.

OPTICAL SUBSYSTEM — FOCAL PLANE INSTRUMENT

REQUIREMENTS	COMMENTS
• LIGHT PICKUPS - NUMBER OF PICKUPS: 32 - CONFIGURATION: TWO LEVELS ENCIRCLING INSTRUMENT IMAGE FIELD - DEGREES OF FREEDOM: EXTENSION AND ROTATIONAL POSITION (ANGLE) FOR EACH PICKUP - RECONFIGURATION TIME (RETRACTION AND REPOSITION) <5 MIN	
• FIBER OPTICS ENTRANCE OPTICS - IRIS (FOCAL PLANE APERTURE): 2 mm SQUARE (10 ARCSEC ON A SIDE) WITH DIAGONALS ALIGNED WITH RULING (PICKUPS ALIGNED RADIALLY) - FABRY LENS: SPECIFICATIONS TBD - MIRROR: SPECIFICATIONS TBD	- OPTICS MOUNTED AT END OF PICKUP ARMS - FABRY LENS IMAGES TELESCOPE OBJECTIVE ON FIBER OPTIC INPUT FACE - MIRROR REDIRECTS LIGHT RADIALLY ALONG PICKUP ARM FOR EFFICIENT PACKAGING OF FIBERS

5.4-2 Focal Plane Instrument (Contd)

The optical fibers route the light from the positionable pickup arms to fixed detectors and scramble light to reduce errors caused by photometric nonuniformities. Each fiber will pass light to a dichroic mirror which will separate light into two color channels. Each channel will feed a separate detector, so that two-color information will be acquired for each star.

OPTICAL SYSTEM — FOCAL PLANE INSTRUMENT (CONTD)

REQUIREMENTS	COMMENTS
• FIBER OPTICS - REFLECTION LOSSES AT ENDS <2% - SPECTRAL REGION OF TRANSMISSIVITY: 4000 TO 8000 Å - TRANSMISSIVITY: >90% IN RED LIGHT (>6000 Å) >80% IN BLUE/YELLOW LIGHT (<6000 Å) - RADIATION EFFECTS: RESISTANT TO CHANGES FOR LONG EXPOSURE TO LEO ENVIRONMENT - LIGHT SCRAMBLING: SPECIFICATIONS TBD	- FUSED SILICA GLASS, GRADED INDEX FIBER DESIGNED FOR HIGH TRANSMISSION OF RED LIGHT.
• FIBER OPTICS EXIT OPTICS - COLLIMATING LENS: F/25 - DICHROIC MIRROR: 45° WITH BANDPASS TUNED TO 6000 Å	

5.4-3 Focal Plane Instrument (Contd)

Separate detectors for each color channel are used. The two color channels selected for the strawman design are blue/yellow (<6000Å) and red (>6000Å). The detector for the flight configuration will be selected later; the strawman design assumed photomultiplier tubes. The basic requirements on the detectors are:

(1) High quantum-efficiency for the two bandpasses — High efficiency yields a great advantage in mission performance in the area of photon statistics and integration time.

(2) Low noise — The noise must be substantially lower than the signal from the faintest star to be observed.

(3) Linear response — Memory, hysteresis, nonlinearity, fat zero, reciprocity failure, and signal-induced background noise are unacceptable.

(4) Spatial stability — Variations in tracking, guiding, or image shape must not affect the signal.

(5) Environments/lifetime — The minimum design life for the detectors is 5 yr. The detectors must withstand the SS electromagnetic environment and must survive and function in the maximum orbital radiation environment.

(6) Operating temperatures — The detectors must not require cooling by consumable cryogens or circulating fluids.

(7) Temporal stability — The absolute sensitivity must not change on time scales of 30 min or less and the spectral response must be stable on a time scale of years even when exposed to light and cycled in temperature many times.

OPTICAL SYSTEM — FOCAL PLANE INSTRUMENT (CONTD)

REQUIREMENTS	COMMENTS
• DETECTOR - NUMBER OF DETECTORS PER PICKUP: TWO - SPECTRAL RANGES: ONE DETECTOR FOR BLUE/YELLOW <6000 Å ONE DETECTOR FOR RED >6000 Å - TYPE: TBD	- A WIDE CHOICE OF DETECTOR TYPES IS AVAILABLE. THE ULTIMATE CHOICE WILL BE MADE AT A LATER DATE. EXPERIMENTAL TRADE STUDIES ARE RECOMMENDED. - FOR THE CASE OF 32 PICKUPS, 64 DETECTORS ARE REQUIRED.

5.4-4 Focal Plane Instrument (Contd)

The visible imager is mounted in the FPI and is used for the following purposes:

1. Collimation and focusing of the primary mirror.
2. Inspection of the primary mirror reflectivity.
3. Inspection of the positioning of the fiber optics input probes.
4. Inspection of the stellar field of view.
5. Inspection for faint neighbors to reference stars.

The imager uses three separate lens groups to satisfy the above purposes:

1. A telephoto lens which provides an image of the telescope objective which fills the detector array.
2. A compression relay lens which images the 10-arcmin-diameter field of view on the detector array.
3. A magnifier which images 20 arcsec of sky onto the detector array.

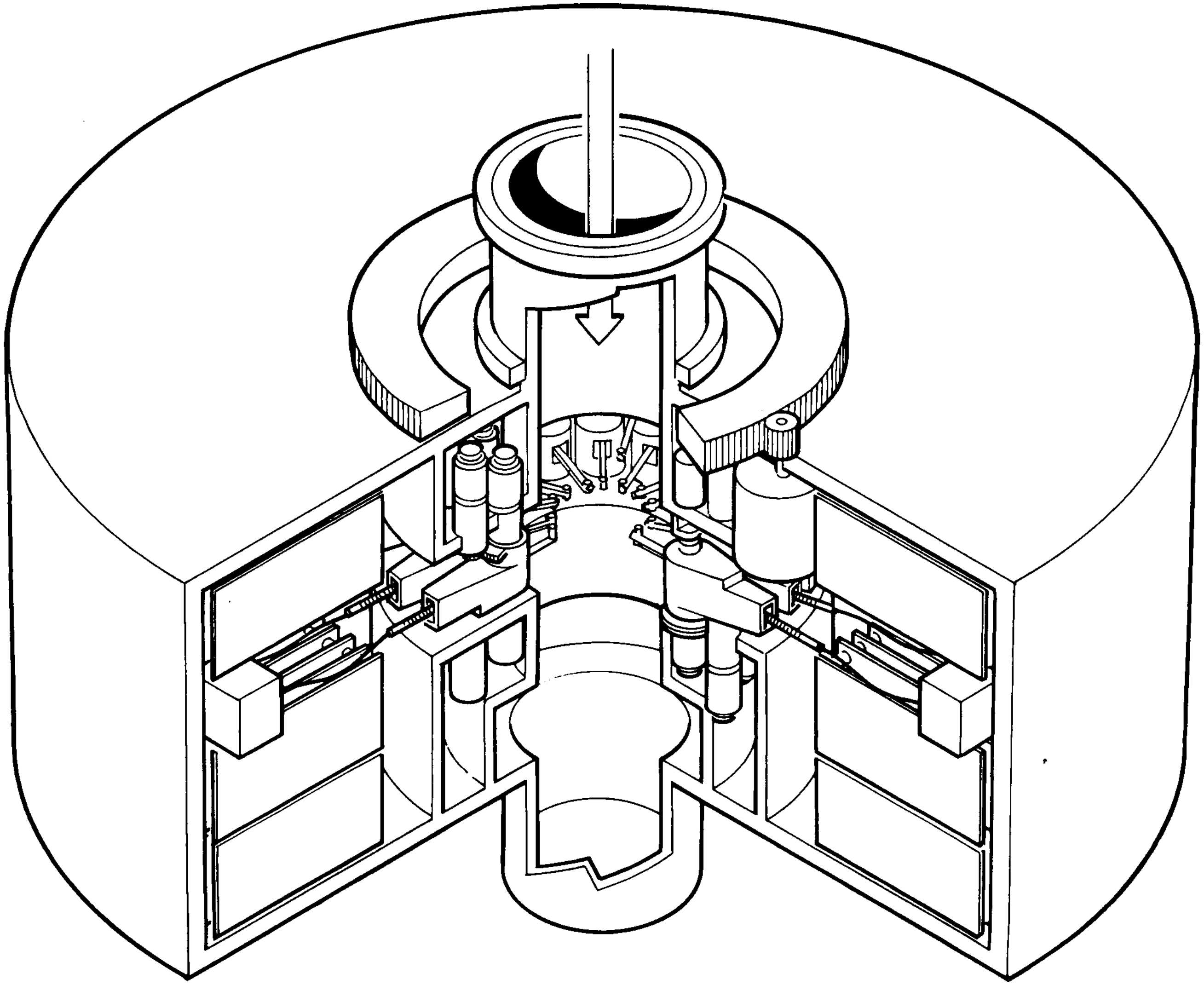
OPTICAL SUBSYSTEM — FOCAL PLANE INSTRUMENT (CONTD)

REQUIREMENTS	COMMENTS
• VISIBLE IMAGER - TELEPHOTO LENS: 450-mm EFL - RELAY LENS: 1/9 SCALE COMPRESSION - MAGNIFYING LENS: 3.5X - PARAFOCALIZE TO ±1 mm - CHANGE LENS GROUPS BY MECHANICAL MOTION - FOCUS ADJUSTED BY MOVING DETECTOR ARRAY - DETECTOR: 512- BY 512-CCD OR EQUIVALENT - PHOTOMETRIC DYNAMIC RANGE >10,000 (SIGNAL-TO-NOISE RATIO) - READOUT NOISE <100 ELECTRON HOLE PAIRS PER PIXEL PER READOUT - SLOW READOUT AT 20,000 PIXEL/SEC LOW NOISE - DETECTOR PASSIVITY COOLED TO -20°C - QUANTUM EFFICIENCY >30% (5000-8000 Å)	- COMMERCIAL CAMERA HEADS AND CCD IMAGERS ARE AVAILABLE WHICH WILL MEET ATF REQUIREMENTS.

5.5 Focal Plane Instrument Diagrams

5.5.1 Isometric View. - This figure shows an artist's concept of the ATF FPI. This unit, except for the detectors, is similar to the MX spectrometer first developed by the University of Arizona in 1980. Current versions of the MX spectrometer are in use at the Steward Observatory. Subsequent charts show working drawings of the ATF FPI along with overall dimensions. The details on this figure will become clearer after the subsequent charts are examined.

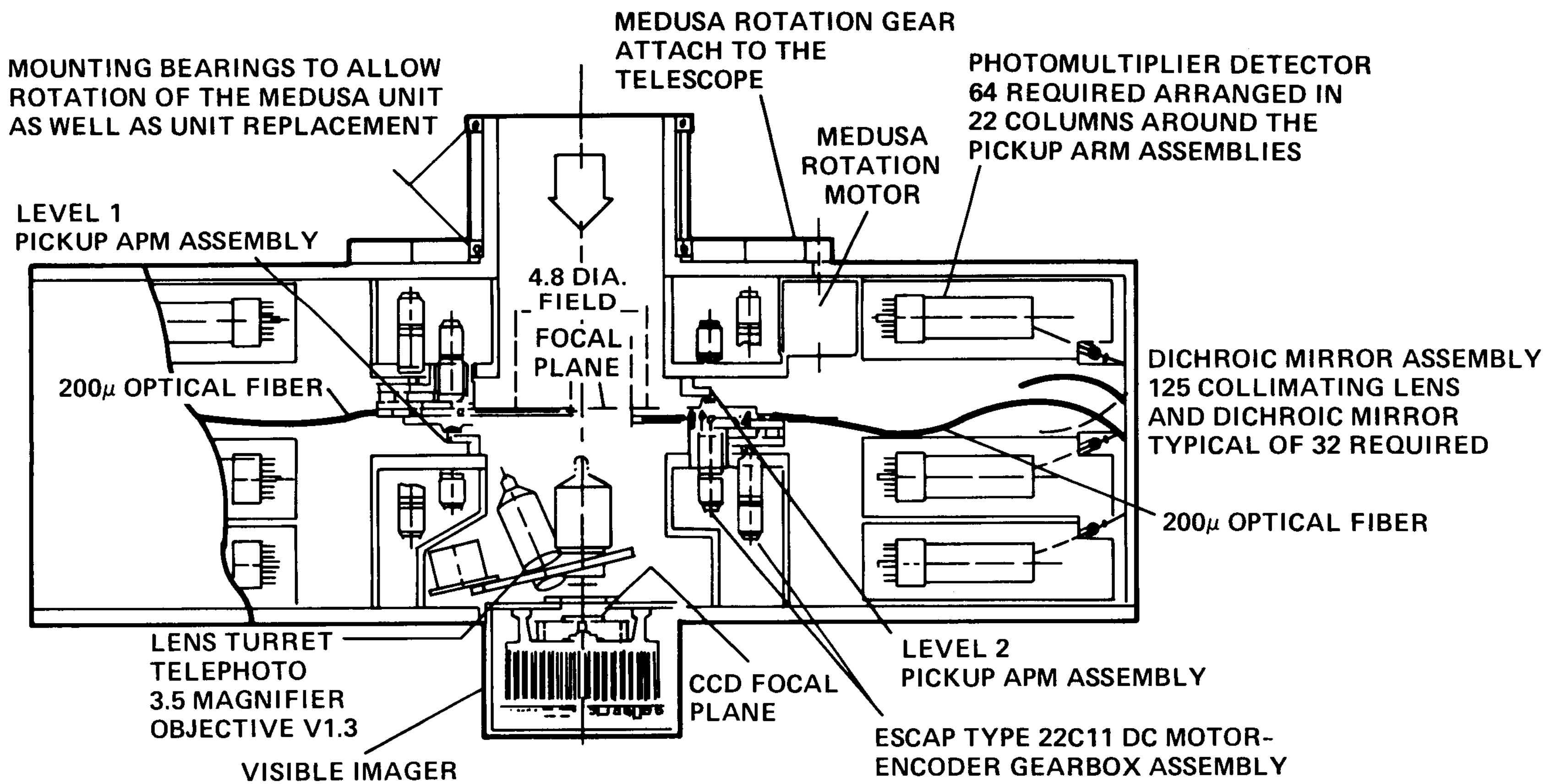
HARDWARE DESCRIPTION
ISOMETRIC VIEW OF ATF FOCAL PLANE INSTRUMENT "MEDUSA"



5.5.2 Focal Plane Instrument — Side View. - This chart shows a side cutaway drawing of the FPI. The major internal components in the unit are labeled. The entire unit is designed to rotate so that pickup heads can be repositioned to cover the same target stars in opposing halves of the image plane. The pickup arms are located at two levels so that the heads can be driven to overlap. Drive motors control the angular and radial positioning of the pickup arms. The visible imager is mounted in the center of the instrument aft of the focal plane.

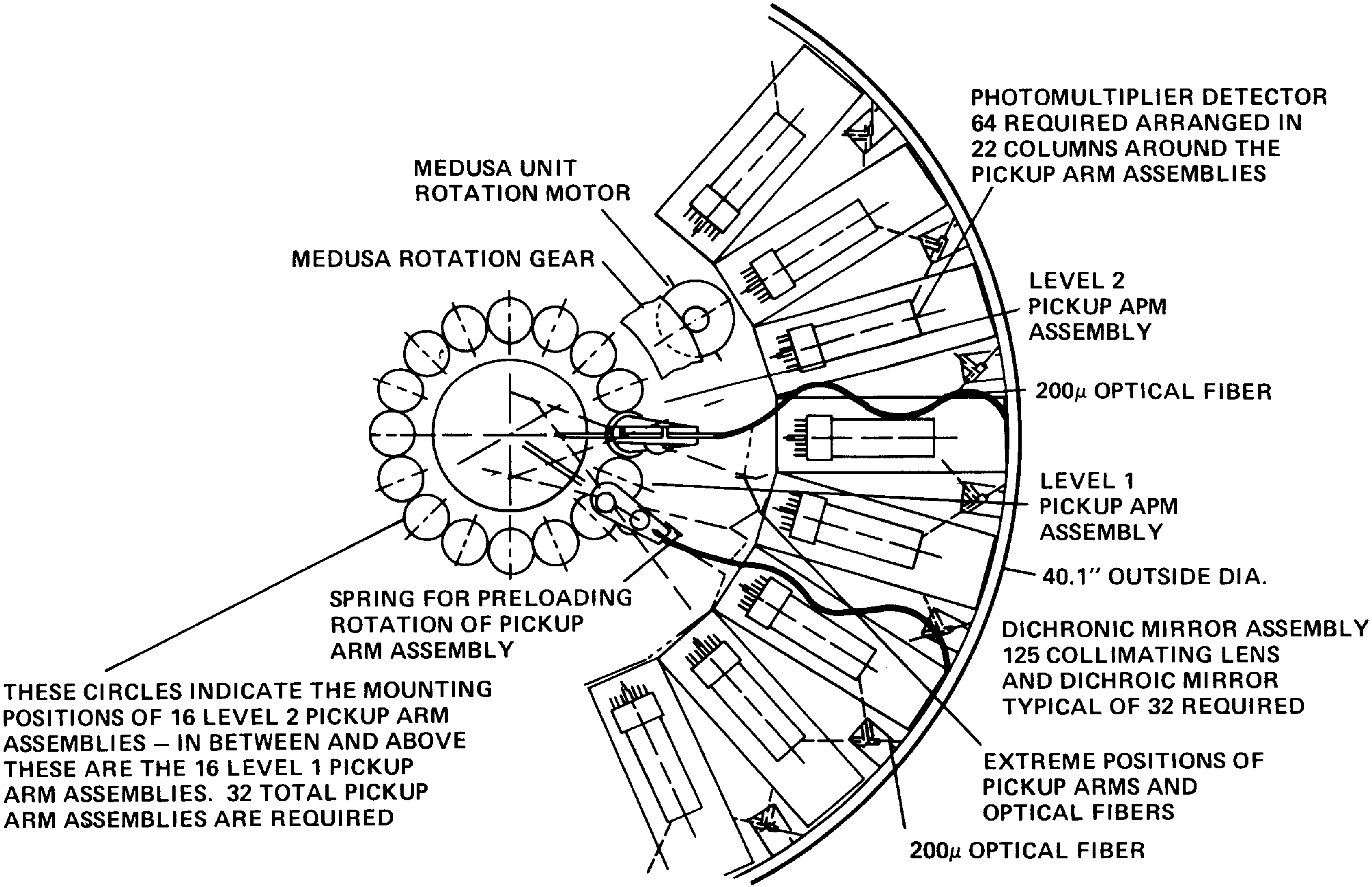
ATF SYSTEMS STUDY

HARDWARE DESCRIPTION
FOCAL PLANE INSTRUMENT — SIDE VIEW



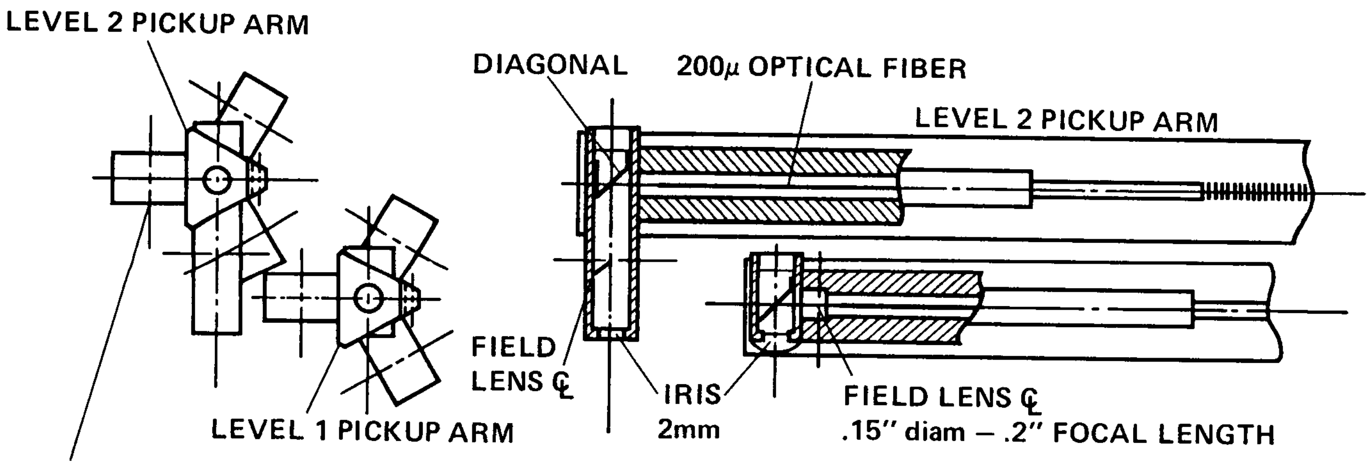
5.5.3 Focal Plane Instrument — Top View. - A top cutaway view of the arrangement of the detectors and pickup arms is shown in this chart. Light from each pickup arm is sent to a dichroic mirror where it is split into two colors and sent to detectors. The instrument consists of two layers of pickup arms, light pipes, and detector assemblies. Only the top layer is shown in this figure.

HARDWARE DESCRIPTION
FOCAL PLANE INSTRUMENT — TOP VIEW



5.5.4 Focal Plane Instrument — Pickup Arm Detail. - This chart shows two views of the entrance ends of the pickup arms. The major elements of the assemblies are identified. Three ball bearing guide wheels positioned at 120° to one another serve as guide rollers when the arms are extended.

HARDWARE DESCRIPTION
FOCAL PLANE INSTRUMENT — PICKUP ARM DETAIL

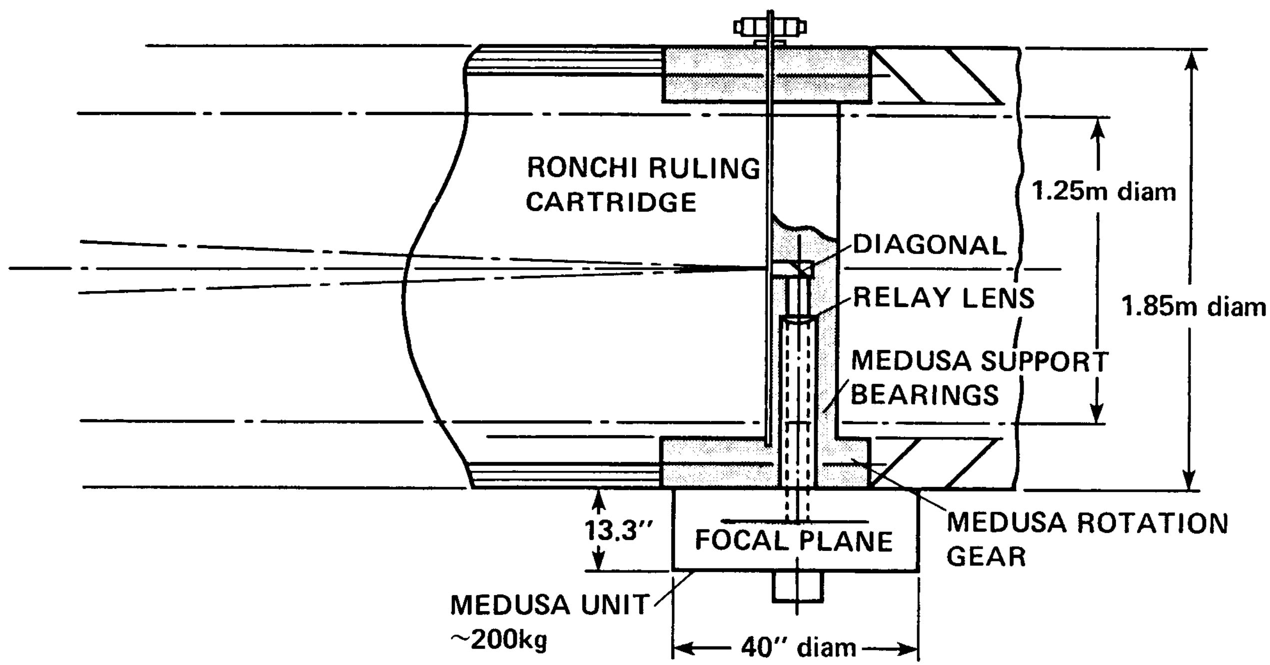


BALL BEARING GUIDE WHEELS FOR TRIANGULAR PICKUP ARMS PIC #E3-149 REQ'D FOR EACH ARM-WHEETS ALONG 2 SIDES ARE FIXED THOSE ALONG THE 3RD SIDE ARE SPRING LOADED

5.5.5 Focal Plane Instrument/Telescope Interface. - This chart shows the overall dimensions of the FPI. The instrument has a diameter of 40 in. and a main body thickness of 13.3 in.

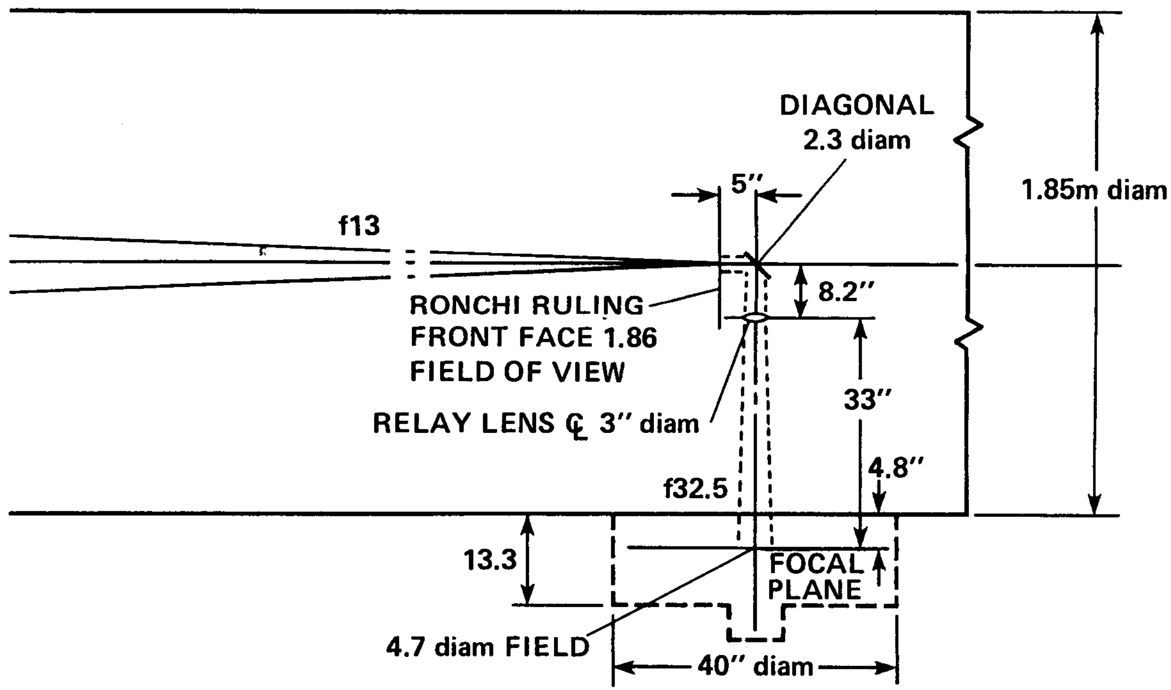
ATF
SYSTEMS STUDY

HARDWARE DESCRIPTION
FOCAL PLANE INSTRUMENT/TELESCOPE INTERFACE



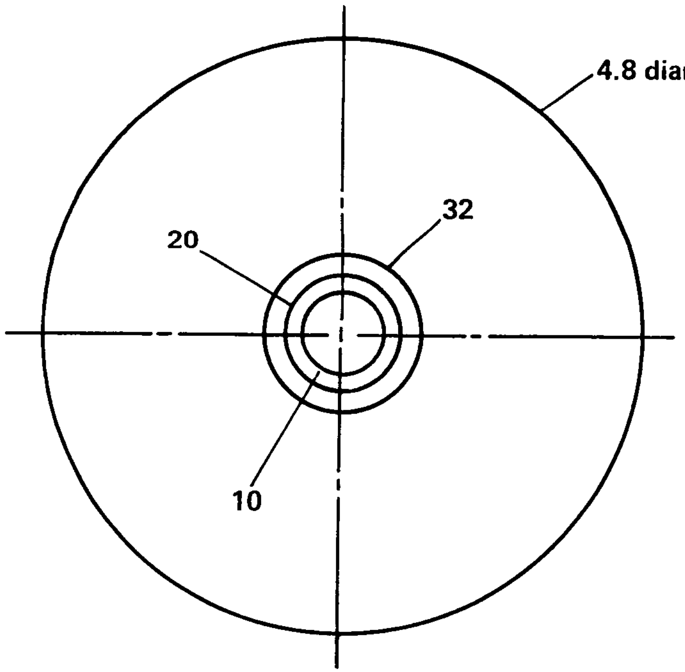
5.5.6 Optical Schematic. - This chart shows the dimensions of the optical paths in the region of the post-focal-plane optics. The lever arms about the relay lens are designed to provide a magnification ratio of 2.5X.

HARDWARE DESCRIPTION
OPTICAL SCHEMATIC



5.5.7 Focal Plane Instrument — Pickup Field Density. - This chart shows the number of pickup arms that can be packaged into various regions of the image plane in the FPI. There are a total of 32 pickup arms in this instrument. The figure illustrates that up to one target star and nine reference stars can be covered in the central region. The allowable packaging densities are constrained by the pickup arm volumes and operating envelopes. However, the possibility that this number of stars of interest falling in a single region of the image plane is remote and can be avoided through judicious choice of the target and reference stars.

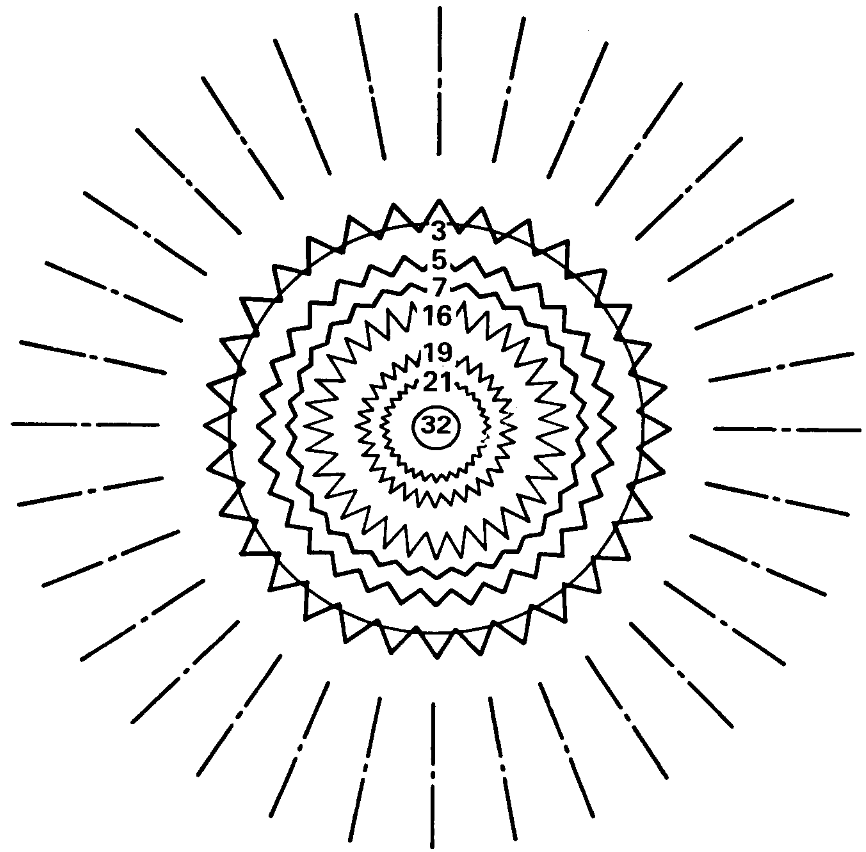
HARDWARE DESCRIPTION
FOCAL PLANE INSTRUMENT — PICKUP FIELD DENSITY



THIS VIEW ILLUSTRATES THE DENSITY OF PICKUP POSITIONS POSSIBLE. 10 PICKUPS CAN BE POSITIONED WITHIN THE #10 LABELED CIRCLE AND ALL 32 WITHIN THE #32 CIRCLE. IN ALL CASES THE OBJECTS MUST BE ~20 arc sec APART. NOTE ALSO THAT THE DENSITY OF PICKUP POSITIONS IS NOT UNIFORM OVER THE INDICATED AREAS

5.5.8 Focal Plane Instrument — Pickup Field Access. - This chart shows the number of pickup arms which can access various regions within the image plane of the FPI. The figure illustrates that the central areas are accessible to all or most of the 32 pickup arms depending on the distance from the center. Only three pickup arms can cover any arbitrary point near the outer edge of the field of view.

HARDWARE DESCRIPTION
FOCAL PLANE INSTRUMENT — PICKUP FIELD ACCESS



NUMBERS INSIDE THE RINGS INDICATE THE NUMBER OF PICKUP ARMS THAT CAN ACCESS ANY POINT INSIDE THAT AREA

5.6 Trades and Open Items

Several approaches exist which may provide an ATF system with enhanced characteristics. The most significant of these items are listed on the adjacent chart and will be the subject of continuing studies.

Some basic theoretical issues surround the character of the ruling that provides the metric information in this astrometry. Further work is required to assess the merit of nonequal line spacing and other geometries such as rulings with nonsquare responses.

Many technical advantages could be derived from the application of folded optics to space astrometry. These systems could alleviate some of the disadvantages of the single-mirror system such as its long tube and relatively small field of view. However, a number of issues need to be explored and solutions to potential problems developed to realize these advantages. Alignment problems and mirror imperfections could threaten the integrity of the measurements. By using a folded optical path, the mirror size can be increased, the physical length of the telescope could be reduced, and the field of view could be expanded.

OPTICAL SUBSYSTEM — TRADE AND OPEN ITEMS

- OPTIMIZATION OF RULING LINE GEOMETRY (CLEAR SPACE WIDTH AND OTHER OPTIMIZATIONS, REQUIRES CAREFUL MODELING TO OPTIMIZE)

- EXAMINATION OF ALTERNATIVE FOLDED OPTICS TWO-MIRROR SYSTEM
  - PROVIDES POTENTIALLY WIDER FIELD WITH MORE BRIGHT REFERENCE STARS
  - PROVIDES HIGHLY SYMMETRICAL COMPACT IMAGES (ELIMINATES COMA)
  - POTENTIALLY GREATER COLLECTING AREA
  - MORE GRACEFUL PACKAGING IN STS BAY
  - HAS POTENTIAL ALIGNMENT AND SECONDARY STABILITY DIFFICULTIES

6.0 ENGINEERING SUBSYSTEMS DESCRIPTION AND REQUIREMENTS

6.1 Structure and Mechanisms Subsystem

6.1.1-1 Requirements/Design Accommodations. - A near optimum focal ratio of f/13 has been selected to keep the comatic and diffraction contributions to image abberration small, and a single-mirror, prime-focus design is chosen to minimize possible systematic errors that would not be amenable to reduction by repeated observations. Taken together, these factors determine the minimum dimensions of the basic telescope structure.

Operational considerations make it impossible to present a single face of the telescope tube to the sun. Hence, a symmetrical sunshade design is chosen. The sunshade length was chosen to be the longest possible while still falling within the launch envelope, and determines the 30° sun avoidance constraint.

Since the telescope length exceeds the shuttle payload bay length, the telescope cannot be launched as a single assembly. The telescope tube is constructed as two separate pieces for launch in order that only a single joint in the optical metering structure need be assembled on orbit.

STRUCTURE AND MECHANISM SUBSYSTEM REQUIREMENTS/DESIGN ACCOMMODATIONS

REQUIREMENT	DESIGN	COMMENTS
ACCOMMODATE OPTICAL DESIGN FOR 1.25-m-DIA PRIMARY MIRROR, F/D=13, CLEAR FOV = 10 ARCMIN	MAINTAIN TELESCOPE TUBE INSIDE DIA ≈ 1.75 m LENGTH ≈ 16.25 m	TOTAL TELESCOPE LENGTH = 21.5 m (WITH SUNSHADE)
PREVENT SCATTERING OF STRAY LIGHT ONTO PRIMARY MIRROR	ANNULAR INTERNAL BAFFLES	
PREVENT DIRECT ILLUMINATION OF APERTURE	SYMMETRIC CYLINDRICAL SUNSHADE; LENGTH = 2.5 m	DETERMINES 30° SUN AVOIDANCE CONSTRAINT
USE A SINGLE SHUTTLE LAUNCH	TELESCOPE TUBE LAUNCHED AS TWO SEPARATE PIECES TO FIT STS PAYLOAD BAY; INDIVIDUAL ASSEMBLIES TO WITHSTAND 9 G, 145 dB ACOUSTIC LOADS	THREE MAJOR SUB-ASSEMBLIES IN SINGLE LAUNCH; ON ORBIT ASSEMBLY REQUIRED

6.1.1-2 Requirements/Design Accommodations (Contd). - After on-orbit assembly, the structure is designed to be sufficiently stable in the presence of expected mechanical and thermal disturbances such that active alignment and control during an observation period is not required. Design provisions are included, however, for alignment and focus adjustments during an initial set-up period and at infrequent intervals during the course of the mission.

The Ronchi ruling is capable of making relative separation measurements between stars in only one axis at a time. Therefore, to determine positions of stars within a field in two dimensions, two orthogonal positions of the telescope about the optical axis are required for each target field. In reality, four positions (arranged in two orthogonal pairs) will be used on each field to minimize systematic errors; this implies the ability to roll the telescope tube about the line of sight over a range of ±180°.

The telescope is provided with an aperture cover which can be closed in response to unplanned contamination events and violations of the Sun avoidance constraints. Since the mission consequences of missing a small number of planned observations are negligible, covering the aperture will be an autonomous function.

STRUCTURE AND MECHANISMS SUBSYSTEM REQUIREMENTS/DESIGN ACCOMMODATIONS (CONTD)

REQUIREMENT	DESIGN	COMMENTS
PRIMARY MIRROR-TO-RONCHI RULING MECHANICAL STABILITY = 15 μ AXIAL, 25 μ LATERAL, 0.1 ARCMIN ROTATIONAL	LARGE DIAMETER MONOCOQUE GRAPHITE-EPOXY TUBE	SAME MATERIAL AS HST OPTICAL TELESCOPE ASSEMBLY. REQUIREMENTS APPLY AFTER ON-ORBIT ASSEMBLY
POSITION ROLL ORIENTATION OVER $\pm 180°$ RANGE FOR ANY LINE OF SIGHT ORIENTATION	ROLL-AXIS DRIVE INCORPORATED INTO VIBRATION ISOLATION/ VERNIER POINTING SYSTEM	
PROVIDE ON-ORBIT TILT, FOCUS, AND DECENTER ADJUSTMENT FOR PRIMARY MIRROR	ELECTROMECHANICAL ACTUATORS ARRANGED IN BIPOD PAIRS	
PREVENT CONTAMINATION OF OPTICAL SURFACES	CLOSABLE APERTURE COVER	
PREVENT INADVERTENT DIRECT SUNLIGHT FOCAL PLANE ILLUMINATION	AUTOMATIC CLOSING OF APERTURE COVER	RESPONDS TO SUN SENSOR

6.1.1-3 Requirements/Design Accommodations (Contd). - The ATF electronics modules are mounted on the telescope tube to eliminate the mechanical disturbances that could be transmitted across the vibration isolation system by cabling. The design approach is to format all the data into a single data stream and transmit it across the vibration isolation system via optical link.

Since it is desirable to move the center of mass of the telescope as close to the primary mirror as possible, most of the electronics are mounted at the extreme aft end on an aluminum structure thermally insulated from the main tube.

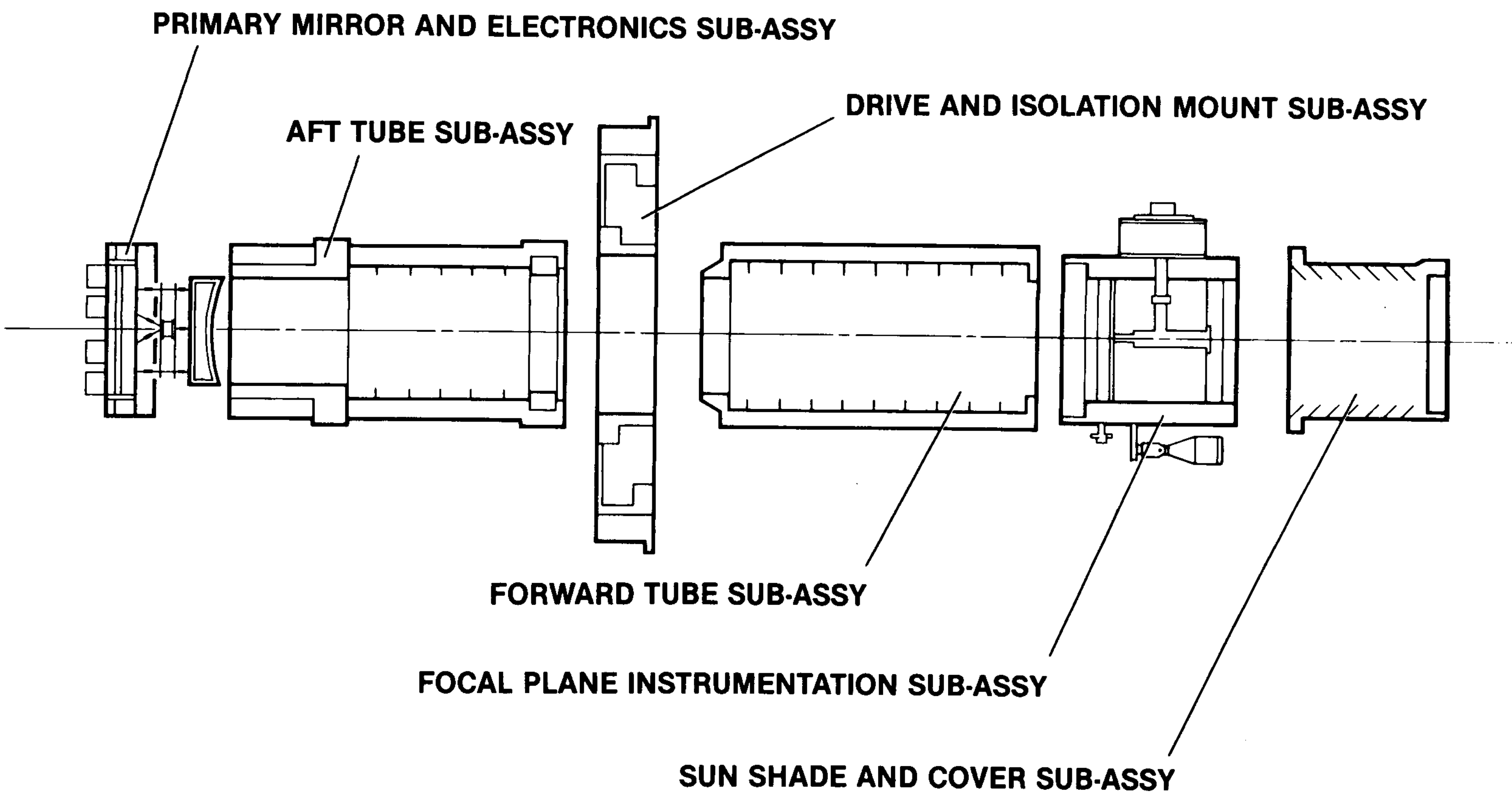
STRUCTURE AND MECHANISMS SUBSYSTEM REQUIREMENTS/DESIGN ACCOMMODATIONS (CONTD)

REQUIREMENT	DESIGN	COMMENTS
PROVIDE MOUNTING ACCOMMODATIONS FOR ELECTRONICS MODULES AND THERMAL CONTROL RADIATOR	STRUCTURAL CHASSIS PLATE AT PRIMARY END OF TELESCOPE, THERMALLY ISOLATED FROM TUBE	MACHINED ALUMINUM PLATE

6.1.2-1 Mechanical Concept. - The ATF basic structure will be fabricated in six subassemblies for ease of manufacture, build up and integration and test. In the launch configuration there will be three major components consisting of: 1) the primary mirror and electronics subassembly joined to the aft tube subassembly, 2) the forward tube subassembly joined to the focal plane instrumentation and sunshade subassemblies, and 3) the Vibration Isolation/Vernier Pointing Subassembly.

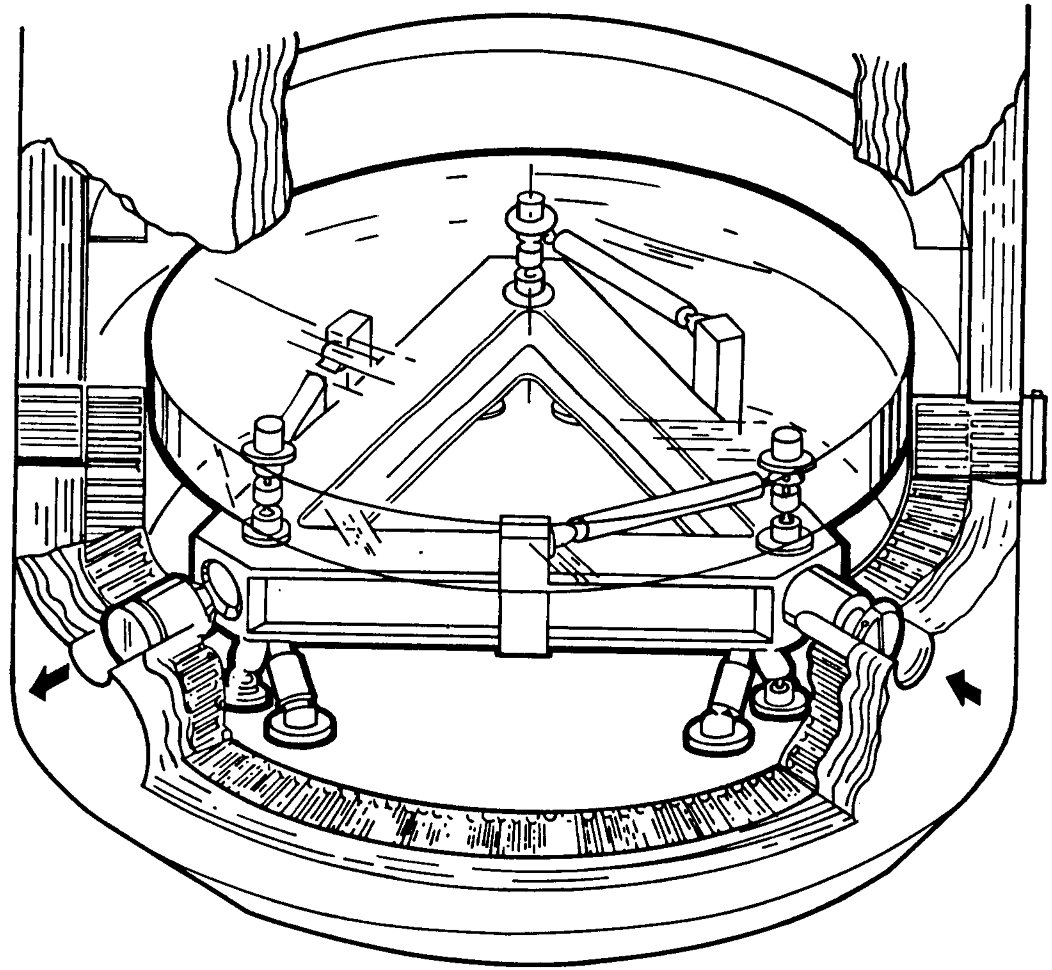
On orbit, the fore and aft tube sections will be mated at a single metallic taper-lock joint integrally cast into the graphite/epoxy tube structure. The tube will then be inserted into the vibration isolator assembly and attached to it with kinematic mounts.

STRUCTURE AND MECHANISMS SUBSYSTEM
MECHANICAL CONCEPT



6.1.2-2 Mechanical Concept (Contd). - The primary mirror is attached to a triangular truss through a system of ground-adjustable reaction links, providing six degrees of freedom of location between the two bodies without inducing any integral stresses in the mirror. For launch and on-orbit assembly operations, the load-bearing truss is caged with respect to the telescope tube structure via three jack screws located in corresponding detents. In operation, a limited range of focus, tilt, and decenter adjustment of the primary mirror is provided by three electromagnetic bipod actuator pairs.

STRUCTURE AND MECHANISMS SUBSYSTEM
MECHANICAL CONCEPT (CONTD)

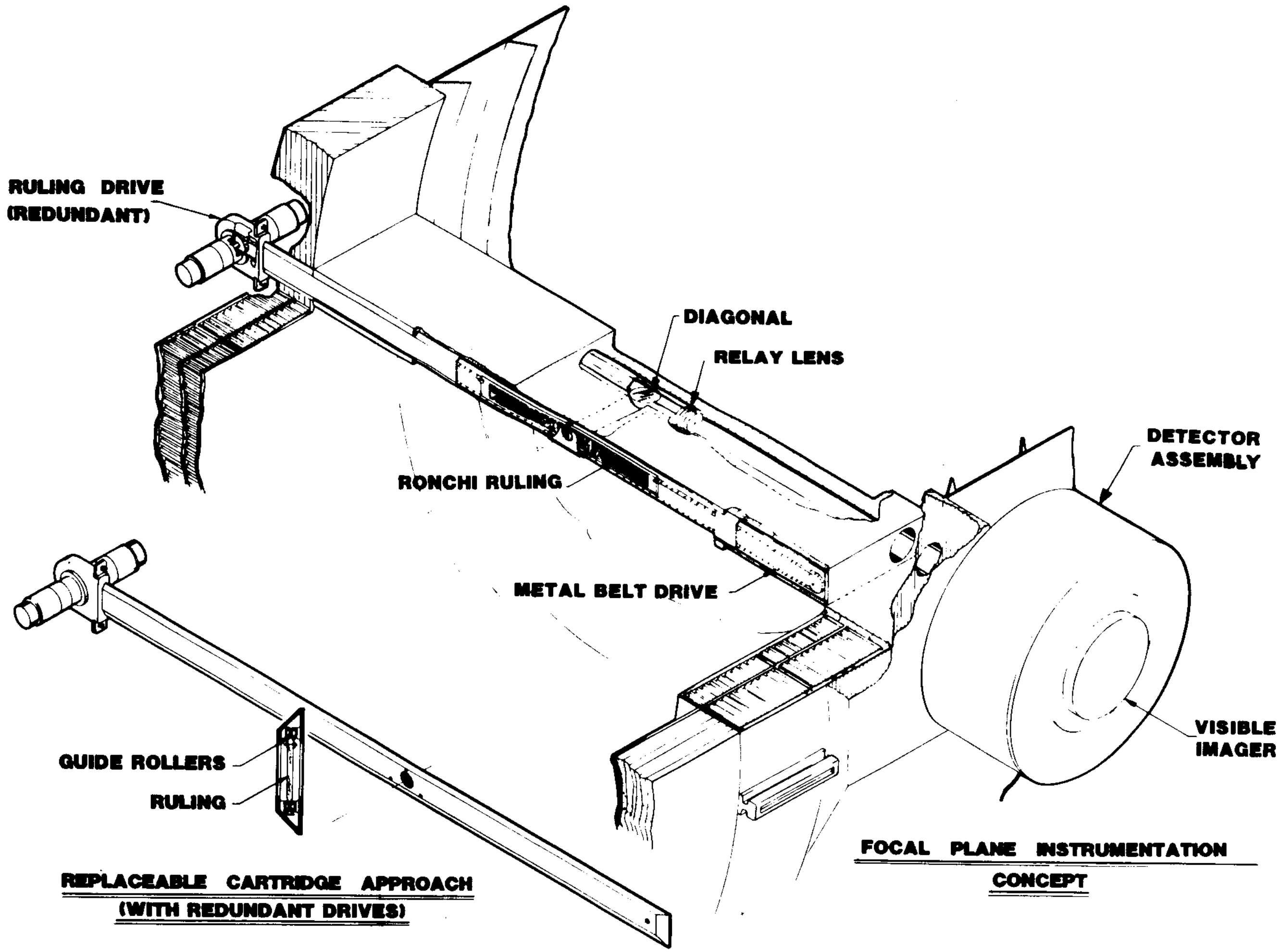


MIRROR MOUNT CONCEPT

6.1.2-3 Mechanical Concept (Contd). - The Ronchi ruling is enclosed in a cartridge which provides mechanical support, protection against contamination, and a drive mechanism. The ruling drive cartridge can be removed and replaced on orbit and will probably be stowed in a separate support structure for launch. The ruling cartridge is supported by a bar structure spanning the telescope tube. This structure also supports the relay optics which direct the light beam from the primary focal plane at the ruling to the FPI. Enclosing the relay optics within the bar structure protects them from contamination.

ATF SYSTEMS STUDY

STRUCTURE AND MECHANISMS SUBSYSTEM MECHANICAL CONCEPT (CONTD)

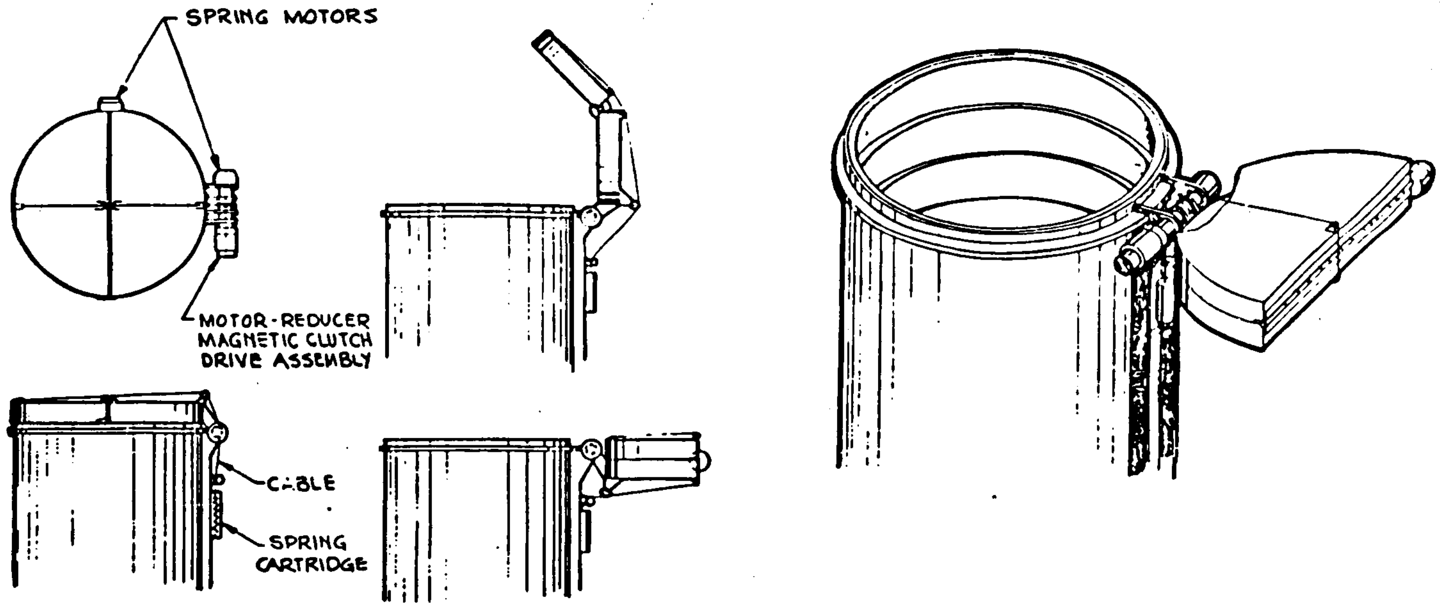


RONCHI RULING DRIVE CONCEPT

6.1.2-4 Mechanical Concept (Contd). - An aperture cover provides protection from contamination during periods when the contamination levels are higher than normal and from the sun in cases when the telescope is pointed incorrectly.

The aperture cover is held in the open position by a redundant-winding motor which drives a cable winch. In the event of a power interruption or a cover-closure command it will be moved to the closed position by redundant spring motors acting through a four-bar linkage. The central hinge is an important design feature which allows the inward-facing surface of the cover to protect itself from accumulating contamination while the aperture is uncovered.

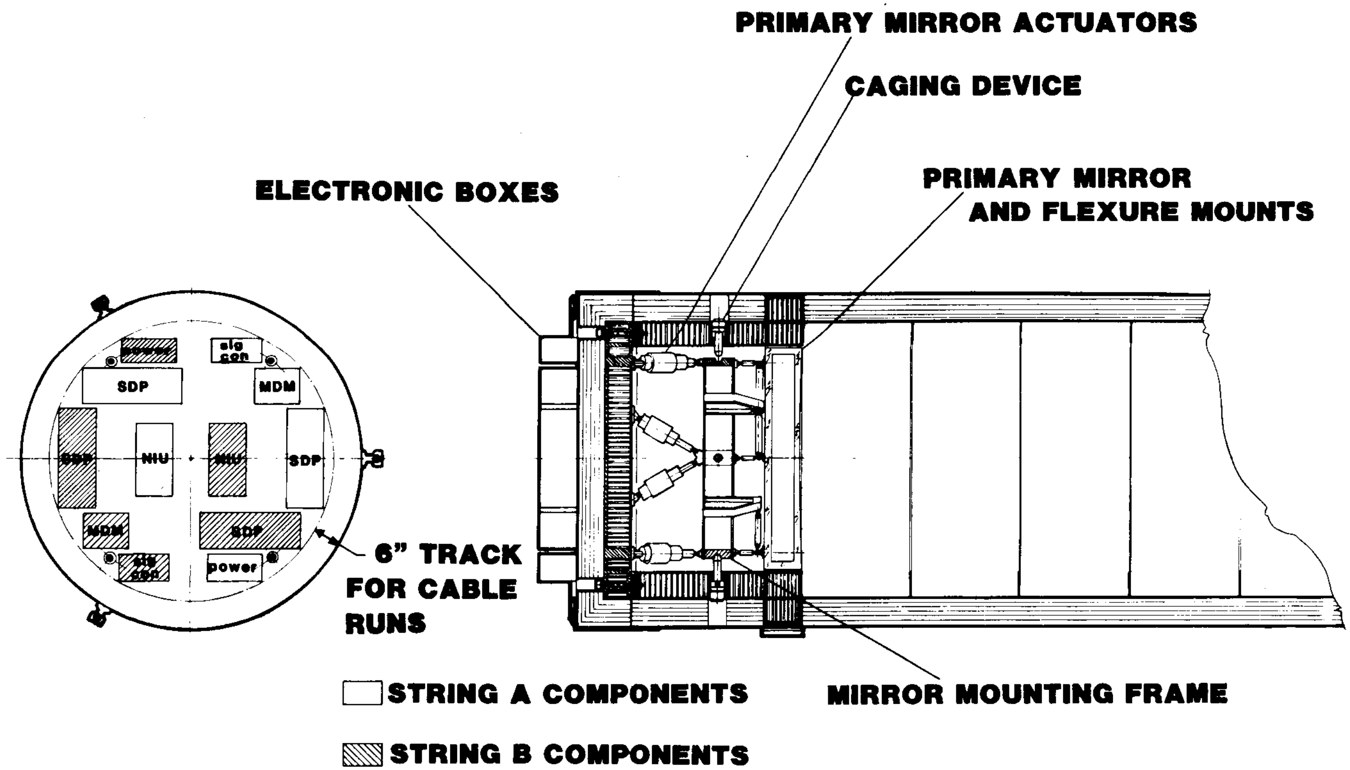
STRUCTURE AND MECHANISMS SUBSYSTEM
MECHANICAL CONCEPT (CONTD)



COVER CONCEPT

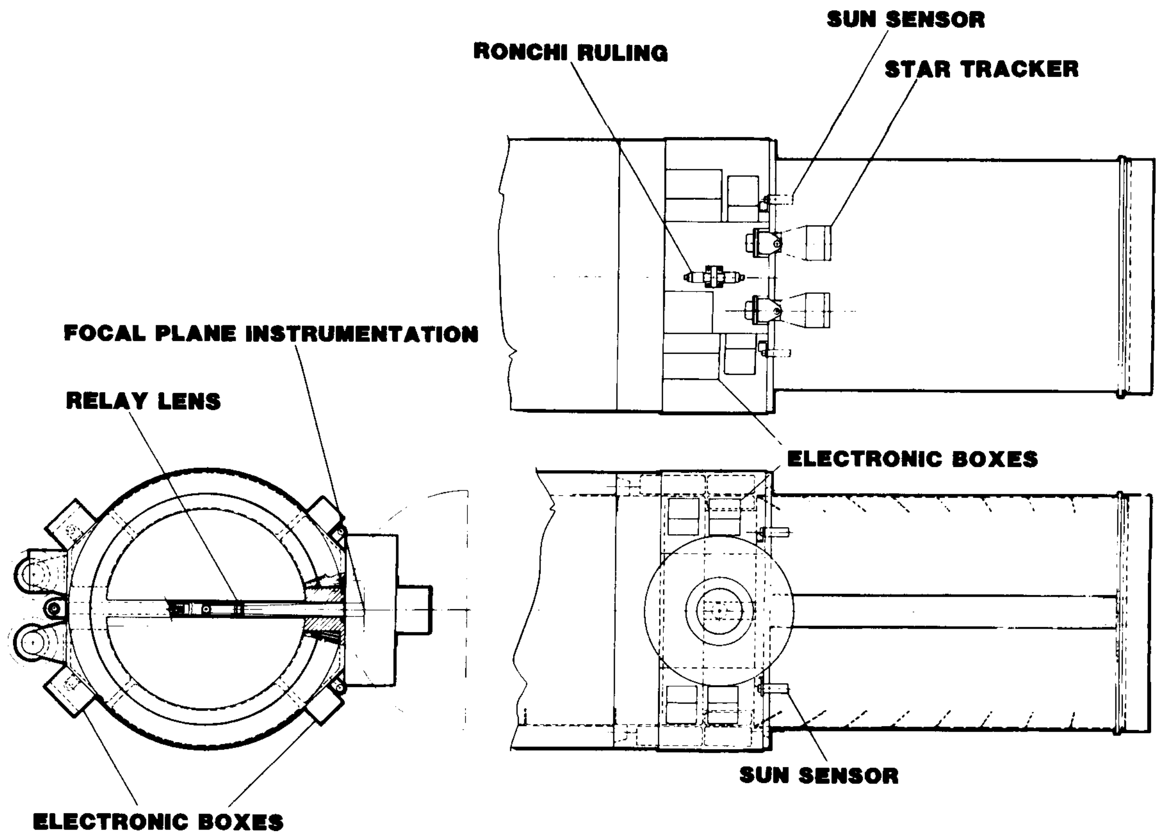
6.1.2-5 Mechanical Concept (Contd). - Most of the command, data, control, and power electronics modules for both the primary and the backup strings can be accommodated on the rear of the telescope. (Two Multiplexer/ Demultiplexers and one signal conditioning unit for each string are located at the front of the tube to interface with the FPI and Star Tracker electronics.) The ATF electronics will be thermally grounded to a circular, machined aluminum plate slightly larger than the outside diameter of the telescope. The mounting plate will itself be thermally grounded to passive radiators extending approximately 0.4 m along and surrounding the telescope tube, but will be otherwise thermally isolated from the telescope structure.

STRUCTURE AND MECHANISMS SUBSYSTEM
MECHANICAL CONCEPT (CONTD)



6.1.2-6 Mechanical Concept (Contd). - The cross section of the front end of the telescope tube will deviate from a simple circular shape by having mounting pads and brackets for supporting the front end electronics. These features will provide simple, stable attachment points for parts of the optics train, the sun shade, the FPI, various sensors, and supporting electronics.

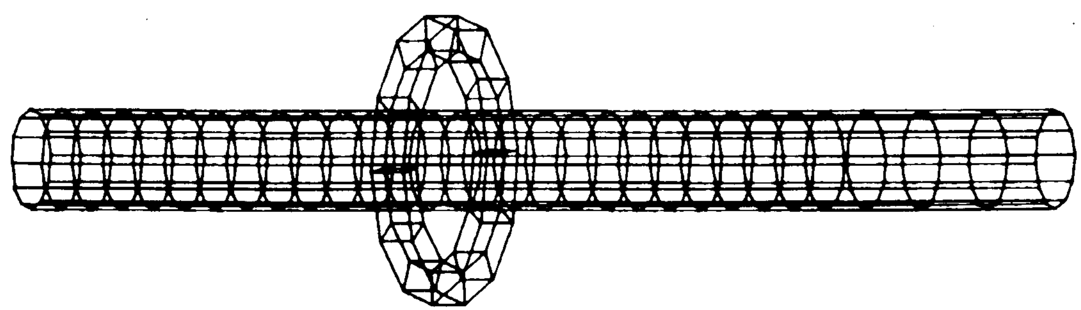
STRUCTURE AND MECHANISMS SUBSYSTEM MECHANICAL CONCEPT (CONTD)



6.1.3 Modeling and Analysis. - To estimate the performance required of the vibration isolation system a simplified finite element model of the telescope was constructed. The model consists of a simple tube with lumped masses at the locations of the primary mirror, the FPI, and the vibration isolator. The tube is assumed constructed of an isotropic material with density and modulus properties equal to the average properties of a multilayer graphite/epoxy composite.

STRUCTURE AND MECHANISMS SUBSYSTEM MODELING AND ANALYSIS

- 350 NODE NASTRAN MODEL
- NATURAL FREQUENCIES FROM 9.4 TO 66 Hz
- 8 MODES RETAINED FOR CONTROL SYSTEM PERFORMANCE STUDY



FIRST BENDING MODE -- 9.4 Hz

6.1.4 Trade and Open Issues. - The design concept for the Ronchi ruling cartridge is a DC motor driving a seamless metal belt attached to the glass ruling. This concept requires further study in regard to its expected fatigue life, potential for generating internal particulate contamination, and physical dynamics.

The telescope tube requires on-orbit assembly and insertion into a close-fitting vibration isolation assembly. This concept requires further study, with particular attention in the areas of extravehicular-activity (EVA) time requirements, mechanical properties of the taper-lock joint, and contamination control during assembly.

STRUCTURE AND MECHANISMS SUBSYSTEM
TRADE AND OPEN ISSUES

- RONCHI RULING DRIVE MECHANISM
  - RELIABILITY
  - STABILITY OF MOTION
- ON-ORBIT ASSEMBLY PROCEDURES

6.2 Thermal Control Subsystem

6.2.1-1 Requirements and Accommodation. - The overall, steady-state, structural-stability requirements are given in volume 1, appendix A. The stated values are based on the overall stability requirements for the optical elements of the telescope. For the present study, the total budget has been divided evenly between mechanical and thermal distortions. The figure shows allowable changes in temperature consistent with this budget and a value of the coefficient of thermal expansion for the telescope tube equal to $1 \times 10^{-7}/°C$. Discussions with one graphite/epoxy supplier indicate values of the coefficient of thermal expansion equal to $0 \pm 0.6 \times 10^{-7}/°C$ can be achieved. The analysis shows that the stability is sufficient relative to axial and lateral motions, and mirror angular motion perpendicular to the optical axis. Verification of the rotation requirement about the optical axis will require a detailed analysis beyond the scope of the present study.

As shown on the figure, the design includes provision for heating the mirror to 20°C above the local structure to minimize condensation of contaminants on the mirror.

THERMAL CONTROL SUBSYSTEM REQUIREMENTS AND ACCOMMODATION

REQUIREMENTS	DESIGN	COMMENTS
• STRUCTURAL STABILITY (THERMAL BUDGET)		
- AXIAL: $\leq 15\mu$ ---> ±9°C	8°C	DESIGN VALUES BASED ON
- LATERAL: $\leq 25\mu$ ---> ±30°C	8°C	GRAPHITE EPOXY WITH COEF
- MIRROR PERPENDICULARITY WITHIN 2×10^{-2} RAD ---> ±185°C	8°C	THERMAL EXPANSION = 1×10^{-7}
- ROTATION ABOUT OPTICAL AXIS 0.1 ARCMIN	TBD	ROTATION STABILITY OF TUBE HIGH, REQUIRES DETAILED ANALYSIS
• CONTAMINATION		
- MIRROR, HEAT 20°C ABOVE LOCAL STRUCTURE	RESISTANCE HEATERS PROVIDED	STANDARD DESIGN

6.2.1-2 Requirements and Accommodation (Contd). - The temperature limits for the engineering subsystem units have been selected as standard values used in other programs. The nonoperating limits for the detectors and preamplifiers in the FPI are also standard electronics values. To reduce noise, the nominal operating temperature for these components has been set at -10°C.

The electronics have been mounted on the telescope, but insulated from the tube. Simple passive radiators have been selected to maintain temperatures within the acceptable ranges. This approach eliminates the need to carry active cooling across the moving joints of the facility, but results in the need to supply power for replacement heaters when the facility is not operating.

Thermal excursions of the Ronchi ruling is a critical requirement which may be difficult to meet. Examination of this question will have to be conducted based on a detailed model of the ruling mechanism and/or empirical laboratory studies with sample ruling substrates.

THERMAL CONTROL SUBSYSTEM
REQUIREMENTS AND ACCOMMODATION (CONTD)

REQUIREMENT	DESIGN	COMMENT
• ELECTRONICS, MOTORS, MECHANISMS		
- OPERATING: -20° TO +50°C - NONOPERATING: -40° TO +50°C	INSULATE COMPARTMENT, CONTROL MOUNTING SURFACE WITH PASSIVE RADIATOR	STANDARD DESIGN REPLACE-MENT HEATERS REQUIRED IF ELECTRONICS OFF
• DETECTORS AND PREAMPS		
- OPERATING: -10°C NOMINAL - NONOPERATING: -40° TO 50°C	ISOLATE COMPARTMENT, CONTROL MOUNTING SURFACE WITH PASSIVE RADIATOR	STANDARD DESIGN REPLACE-MENT HEATER REQUIRED IF ELECTRONICS OFF
• RONCHI RULING		
- 0.16°C STABILITY ON A SPATIAL SCALE OF 100 mm IN 2 MIN	TBD	REQUIRES DETAILED THERMAL MODEL AND/OR EXPERIMENT

6.2.2 Thermal Analyses.

6.2.2.1 Description: The analyses conducted during the study were; 1) to determine structural distortions associated with varying Earth and solar illumination during the mission and 2) to define the size of passive radiators and replacement heater requirements. The analyses use a simple first-order approach based on equilibrium conditions only. Transient analyses will be required in future studies.

THERMAL CONTROL SUBSYSTEM
THERMAL ANALYSES — DESCRIPTION

- SIMPLE FIRST-ORDER ANALYSES ON BOUNDING CASES ONLY (EQUILIBRIUM FULL SUN AND EARTH ALBEDO OR ECLIPSE)
- CASES ANALYZED
  - STRUCTURAL STABILITY OF TELESCOPE TUBE FOR OPTICAL REQUIREMENTS
  - RADIATOR SIZE AND REPLACEMENT HEAT REQUIREMENTS FOR ELECTRONICS MOUNTED ON TELESCOPE
    - AFT END
    - FORWARD END ELECTRONICS
    - VIBRATION ISOLATION SYSTEM
  - HEAT REQUIRED TO KEEP MIRROR 20°C ABOVE LOCAL TEMPERATURES
- RONCHI RULING STABILITY NOT ADDRESSED — REQUIRES DETAILED DEFINITION OF MECHANISM AND DETAILED MODEL

6.2.2.2 Assumptions: The assumed conditions and H/W characteristics, and the results of the analyses are presented in this and the following five figures.

THERMAL CONTROL SUBSYSTEM
THERMAL ANALYSES — ASSUMPTIONS

- DESIGN APPROACH: MINIMIZE TUBE SENSITIVITY TO TEMPERATURE VARIATIONS
  - GRAPHITE/EPOXY FABRICATED WITH THERMAL COEFFICIENT OF EXPANSION $0 \pm 0.6 \times 10^{-7}$ /°C MANUFACTURES CLAIM (1×10^{-7} /°C USED IN ANALYSIS)
  - BLANKET TUBE
- ENVIRONMENTAL INPUTS
  - SOLAR CONSTANT: 1300 W/m^2
  - EARTH ALBEDO: 0.3
  - EARTH BLACKBODY TEMPERATURE: 240°K
  - ORBIT PERIOD: 90 MIN
  - MAXIMUM ECLIPSE: 35 MIN
  - MINIMUM ECLIPSE: 25 MIN

6.2.2.3 Structural Analysis : This page intentionally left blank.

THERMAL CONTROL SUBSYSTEM
STRUCTURAL ANALYSIS

- HARDWARE CHARACTERISTICS
  - BLANKET SURFACE: $\varepsilon = 0.75, \quad \alpha = 0.4$
  - BLANKET EFFECTIVE EMISSIVITY: 0.025
  - TUBE THERMAL COEFFICIENT OF THERMAL EXPANSION: 1×10^{-7}
  - TUBE SPECIFIC HEAT: 950 J/Kg•°C
  - TUBE WALL THICKNESS: 0.64 cm
- RESULTS
  - ORBIT AVERAGE TEMPERATURE
    - MAXIMUM ECLIPSE: 226°K
    - MINIMUM ECLIPSE: 234°K
  - WORST-CASE TEMPERATURE CHANGE DURING ORBIT: 8°C

6.2.2.4-1 Electronics Power Dissipation: This page intentionally left blank.

THERMAL CONTROL SUBSYSTEM
ELECTRONICS POWER DISSIPATION

- ELECTRONICS AT AFT END AND AT FPI
  - DESIGN APPROACH
    - SIMPLE PASSIVE RADIATORS FOR POWER DISSIPATION
    - REPLACEMENT HEATERS WHEN ELECTRONICS OFF
  - ENVIRONMENTAL INPUTS — SEE STRUCTURAL ANALYSIS
  - RADIATOR SURFACE CHARACTERISTICS: $\varepsilon = 0.8$, $\alpha = 0.1$
  - RESULTS: AFT RADIATOR (ELECTRONICS P6OWER 640 W)
    - RADIATOR DIMENSIONS (m): 1.85 DIA BY 0.375 LONG
    - MAXIMUM TEMPERATURE: 22°C
    - MINIMUM TEMPERATURE: 10°C
    - REPLACEMENT HEATERS (ELECTRONICS OFF): 407 W
  - RESULTS: FORWARD RADIATOR (ELECTRONICS POWER 268)
    - RADIATOR DIMENSIONS (m): 1.85 DIA BY 0.22 LONG
    - MAXIMUM TEMPERATURE: +2°C
    - MINIMUM TEMPERATURE: -13°C
    - REPLACEMENT HEATERS (ELECTRONICS OFF) 239 W

6.2.2.4-2 Electronics Power Dissipation (Contd): This page intentionally left blank.

THERMAL CONTROL SUBSYSTEM
ELECTRONICS POWER DISSIPATION (CONTD)

- VIBRATION ISOLATION/VERNIER POINTING SYSTEM
  - DESIGN APPROACH
    - USE SURFACE BETWEEN TUBE AND POINTING MOUNT FOR RADIATOR
    - REPLACEMENT HEATERS WHEN SYSTEM OFF
  - ENVIRONMENTAL INPUTS — SEE STRUCTURAL ANALYSIS
  - RADIATING SURFACE CHARACTERISTICS: $\varepsilon = 0.4$, $\alpha = 0.1$
  - RESULTS (POWER DISSIPATED 420 W AVERAGE)
    - RADIATING AREA: $2\ m^2$
    - MAXIMUM TEMPERATURE: 29°C
    - MINIMUM TEMPERATURE: -7°C
    - REPLACEMENT HEATER (ELECTRONICS OFF): 374 W

6.2.2.5 Mirror Heating Analysis: This page intentionally left blank.

THERMAL CONTROL SUBSYSTEM
MIRROR HEATING ANALYSIS

- APPROACH TO MIRROR CONTAMINATION
  - MAINTAIN MIRROR 20°C ABOVE LOCAL SURFACE
- ENVIRONMENTAL INPUTS
  - TELESCOPE TUBE ESSENTIALLY BLACK BODY AT 230°K
- MIRROR CHARACTERISTICS
  - SIZE (m): 1.25 DIA, 0.15 THICK
  - ALL SURFACES: $\varepsilon = 0.5$
- RESULTS
  - POWER FOR 20° DELTA: 96 W

6.2.3 Thermal Control Hardware. - Hardware is designed specifically for ATF use from existing space qualified technology and components.

THERMAL CONTROL SUBSYSTEM HARDWARE

- HARDWARE CUSTOM DESIGNED FOR ATF MISSION
- DESIGNS BASED ON STANDARD THERMAL MATERIALS AND PROCESSES

6.2.4 Trades and Open Issues. - This page intentionally left blank.

THERMAL CONTROL SUBSYSTEM
TRADES & OPEN ISSUES

- RULING THERMAL STABILITY
  - REQUIRES DETAILED MODEL
  - TIGHT STABILITY REQUIREMENTS

- TRADE ACTIVE COOLING (SS UTILITY) VERSUS PASSIVE SYSTEM (STRAWMAN)

6.3 Command and Data Subsystem

6.3.1 Requirements/Design Accommodation. - The general requirements for the ATF Command and Data Subsystem (CDS) can be separated into four categories:

1. Data Collection
2. Data Return
3. Telescope Control
4. Contingency Operations

It is assumed that all SS Data Management System (DMS) element designs anticipated to be used by the ATF will be available in time for ATF use. This assumption should be valid since these SS elements are required to be available very early in the station build up.

COMMAND AND DATA SUBSYSTEM REQUIREMENTS/DESIGN ACCOMMODATION

COMMAND AND DATA SUBSYSTEM TASK SUMMARY

- DATA COLLECTION
- DATA RETURN
- TELESCOPE CONTROL
- CONTINGENCY OPERATIONS

6.3.1.1 Data Collection: For data collection, the CDS must provide the data paths necessary to acquire data from a variety of sensors differing in type, physical location, and signal characteristics. The ATF achieves this requirement through the use of generic components to be developed for the SS DMS.

In acquiring and processing data from ATF onboard sensors, the primary component is the DMS Multiplexer/Demultiplexer (MDM). A single MDM will multiplex data from as many as 160 digital sources or 512 analog sources, allowing a throughput of 2 Mbps from a single source or a 10-Mbps aggregate rate from all sources. It is anticipated that the ATF will use a combination of digital and analog channels, digital channels being used for photon counts and accelerometer readouts, and analog channels for temperature and voltage readings. The baseline CDS definition calls for the use of three MDM's, allowing 25% margin for an increase in the number of sensors or a decrease in the anticipated MDM performance.

The ATF will also be required to acquire and process data from external sources. These data will include such information as SS warning signals, attitude, and time code. The ATF acquires these data by means of an onboard command and data handling processor which monitors the SS local network. The proposed processor is the SS developed Standard Data Processor (SDP), which interfaces to the SS network through a generic SS Network Interface Unit (NIU).

With data access paths established, the CDS is required to be capable of sampling data in multiple formats during the course of normal operation. In addition to the standard astrometric observational mode, ATF operations will include imaging, environmental characterization (e.g., high rate sampling of accelerometer or temperature sensor data), and memory readout. This flexibility, as well as the ability to provide for unforeseen troubleshooting activities, is provided for by the SS requirement that the MDM be onboard programmable.

COMMAND AND DATA SUBSYSTEM REQUIREMENTS/DESIGN ACCOMMODATIONS

REQUIREMENTS	DESIGN	COMMENTS
• DATA COLLECTION		
- ATF ONBOARD SOURCES 64 PMTs 96 PROBE POSITION SENSORS 256 TEMP/VOLT SENSORS 32 ACCELEROMETERS 1 IMAGER TOTAL - 449 CHANNELS	- THREE SS MULTIPLEXER/DEMULTIPLEXERS (MDMs) - PROVIDES FOR 130 DIGITAL/ 704 ANALOG CHANNELS	- USE OF DESIGN DEVELOPMENT BY SS SAVES HARDWARE DEVELOPMENT COSTS
- EXTERNAL SOURCES SS ENGINEERING & ALARMS POINTING CONTROL DATA	- INTERFACE VIA A LOCAL DATA NETWORK - ACCESS TO ALL DATA ON THE NET	- NETWORK INTERFACE VIA SS DESIGNED HARDWARE AND SOFTWARE
- ASTROMETRIC OBSERVATION IMAGING ENVIRONMENTAL CHARACTERIZATION MEMORY READOUT	- MDMs ARE ON-BOARD PROGRAMMABLE - NETWORK INTERFACE ALLOWS VARIABLE DATA RATES	- SINGLE FOCAL PLANE INSTRUMENT SIMPLIFIES DATA FORMATTING

6.3.1.2 Data Return: The data return task is driven by the need to downlink astrometric data in real time. The ATF baseline design accomplishes this requirement with a downlink rate of 1.75 Mbps, equal to the maximum anticipated data acquisition rate. The use of standard SS-developed equipment does not become limiting until a rate of 10 Mbps is reached, thus providing a good margin against ATF requirements.

The ATF data quality requirement of bit error rates (BER) less than 10^{-6} appears readily achievable through the use of standard digital data handling techniques. The requirement currently carried by the SS is for a BER of less than 10^{-8} from the time the data is placed onto the local network to the time the data is delivered to the Ground Operations Center.

COMMAND AND DATA SUBSYSTEM REQUIREMENTS/DESIGN ACCOMMODATIONS

REQUIREMENTS	DESIGN	COMMENTS
• DATA RETURN		
- REALTIME DATA DOWNLINK 17.5-1750 Kbps 50% DUTY CYCLE	- 1750 Kbps DATA RATE	- THE SS ELEMENTS ARE ABLE TO SUPPORT UP TO 10 Mbps PROVIDING SUBSTANTIAL MARGIN
- DATA QUALITY: BER $< 10^{-6}$	- THE ATF USES STANDARD DIGITAL DATA HANDLING	- THE SS LINK IS SPEC'D AT $< 10^{-8}$
- DATA STORAGE	- NOT REQUIRED	- AVAILABLE FOR CONTINGENCY

6.3.1.3-1 Telescope Operational Control: Telescope operational control consists of those tasks which determine the overall operation of the telescope. These tasks include initiation and termination of observations, alarm monitoring, command execution, etc. To accomplish these functions the ATF proposes to use the previously described SS SDP. This is defined to operate at speeds up to 4 MIPS, and contain up to 32 MB of memory, capabilities which are felt to be more than adequate for the ATF control tasks.

The SDP would control the data input/output, monitor engineering data for hazardous conditions, respond simply and appropriately to anomalous conditions, and accept and execute commands and command sequences. The baseline requirement for ATF command rate is that a full memory load be accomplishable via a single TDRS link. This translates into an uplink requirement of between 5 and 150 Kbps, well within the planned SS rates of approximately 12 Mbps.

COMMAND AND DATA SUBSYSTEM REQUIREMENTS/DESIGN ACCOMMODATIONS

REQUIREMENTS	DESIGN	COMMENTS
• TELESCOPE OPERATIONAL CONTROL		
- ACTIVE OPERATIONAL CONTROL	- ON-BOARD COMMAND AND DATA HANDLING PROCESSOR - SS DEVELOPED SDP PROVIDES SIGNIFICANT PROCESSING AND MEMORY MARGIN	- REQUIREMENT MET BY USE OF STANDARD SS H/W
- COMMAND RATE: UPLINK MUST SUPPORT A FULL MEMORY LOAD DURING A SINGLE TDRS LINK 5-150 Kbps	- USE OF STANDARD SS HARDWARE DESIGNED TO SUPPORT NOMINAL RATES OF 12 Mbps	- REQUIREMENT MET BY USE OF STANDARD SS H/W

6.3.1.3-2 Telescope Operational Control (Contd): The timing requirement of the ATF control function is anticipated to be met by the use of SS Master Time and Frequency Generation System (TGS). This system as currently described will supply a segmented time code once each second, and a stable reference (TBD, but >1 MHz) to be used for finer time resolution. The ATF requirement is that the execution of control events be schedulable within an accuracy of 1 μsec during the course of a single scan of the Ronchi ruling. A single scan can take as long as 20 min, therefore a clock stability of approximately 8×10^{-10} is required. The current SS TGS definition calls for a clock stability of 1×10^{-13} over a period of 1 day, thereby satisfying the ATF requirement.

Telescope control will also require provisions for astronaut on-board control and display. This requirement is met by the incorporation of an ATF control console in the baseline design to be located somewhere in the pressurized modules. This control console would allow for the immediate execution of discrete commands (such as a power-off function) through front panel switches, as well as more intricate control via sequence commanding. The baseline design calls for the use of another SS-developed piece of H/W, an Embedded Data Processor (EDP), as the means of processing telescope engineering data and generating command sequences. For command sequencing, the astronaut would interface to the ATF control console by means of any of the planned SS Multi Purpose Applications Consoles (MPACs). The MPAC would provide remote terminal access to the ATF control console.

COMMAND AND DATA SUBSYSTEM REQUIREMENTS/DESIGN ACCOMMODATIONS

REQUIREMENTS	DESIGN	COMMENTS
- TIMING: EVENT SCHEDULING TO WITHIN 1 µSEC ACCURACY DURING A SINGLE SCAN	- THE SS MASTER TIME AND FREQUENCY GENERATION SYSTEM PROVIDES GREATER THAN 1 µSEC ACCURACY	- THE ATF TIMING STABILITY REQUIREMENTS ARE WELL WITHIN CURRENT TECHNOLOGY LIMITS, AS PLANNED FOR THE SS
- ON-BOARD CONTROL AND DISPLAY	- THE ATF CONTROL CONSOLE IS MOUNTED IN A PRESSURIZED MODULE	- DISCRETE EVENT SWITCHES AND SERIAL COMMAND INPUTS ARE PROVIDED - USES SS DEVELOPED H/W

6.3.1.4 Contingency Operations: The ATF must provide the capability for contingency operations in the event of failures and/or prolonged or chronic loss of downlink.

The command and data subsystem has been designed as a dual string system, compatible with the overall system approach described in section 4.9.

Space Station data storage services have been requested to offer protection from temporary short term downlink outages, such as might occur in the event of another user occupying the full downlink capability during a bulk memory transfer. The ATF request for SS data storage services is based on the assumption that it may become necessary to store as much as one orbit of observations before normal downlink services are available.

In the event of long term or chronic loss of downlink, the ATF baseline design provides a contingency data reduction processor. This processor would provide onboard data reduction thereby reducing the data bulk by two to five orders of magnitude, allowing the ATF to operate for substantial periods without a downlink, or to downlink data at a greatly reduced data rate. This on-board data reduction is planned for contingency use only as the original data, and therefore considerable information is lost in the data reduction processing, which leads to an increased risk of introducing systematic errors. At present, a specific processor for this task is unidentified. Candidate data reduction algorithms currently exist, but must still be scaled and optimized for ATF operations. Selection of a candidate data reduction processor will occur after the details of the processing task are more fully defined.

COMMAND AND DATA SUBSYSTEM REQUIREMENTS/DESIGN ACCOMMODATIONS

REQUIREMENTS	DESIGN	COMMENTS
• CONTINGENCY OPERATIONS		
- REDUNDANCY	- DUAL STRING DATA HANDLING	- MINIMAL CROSS-STRAPPING REDUCES COST
- TEMPORARY DATA STORAGE OF ATF DATA - 1.0 Gbit	- USE OF SS STANDARD DATA STORAGE SERVICES - 1.0 Gbit STORAGE REQUESTED	- PROVIDES PROTECTION AGAINST TEMPORARY DOWNLINK OUTAGES
- ON-BOARD DATA REDUCTION TO EASE DOWNLINK REQUIREMENT	- A DATA REDUCTION PROCESSOR REDUCES THE DATA ALLOWING EFFICIENT DATA STORAGE AND/OR LOW DOWNLINK RATES DURING CONTINGENCY OPERATIONS	- PROVIDES PROTECTION AGAINST EXTENDED/ CHRONIC DOWNLINK OUTAGES

6.3.2 Subsystem Description. - The ATF CDS baseline design consists of a distributed system with elements both on the telescope tube and inside a pressurized module, and makes substantial use of standard SS services.

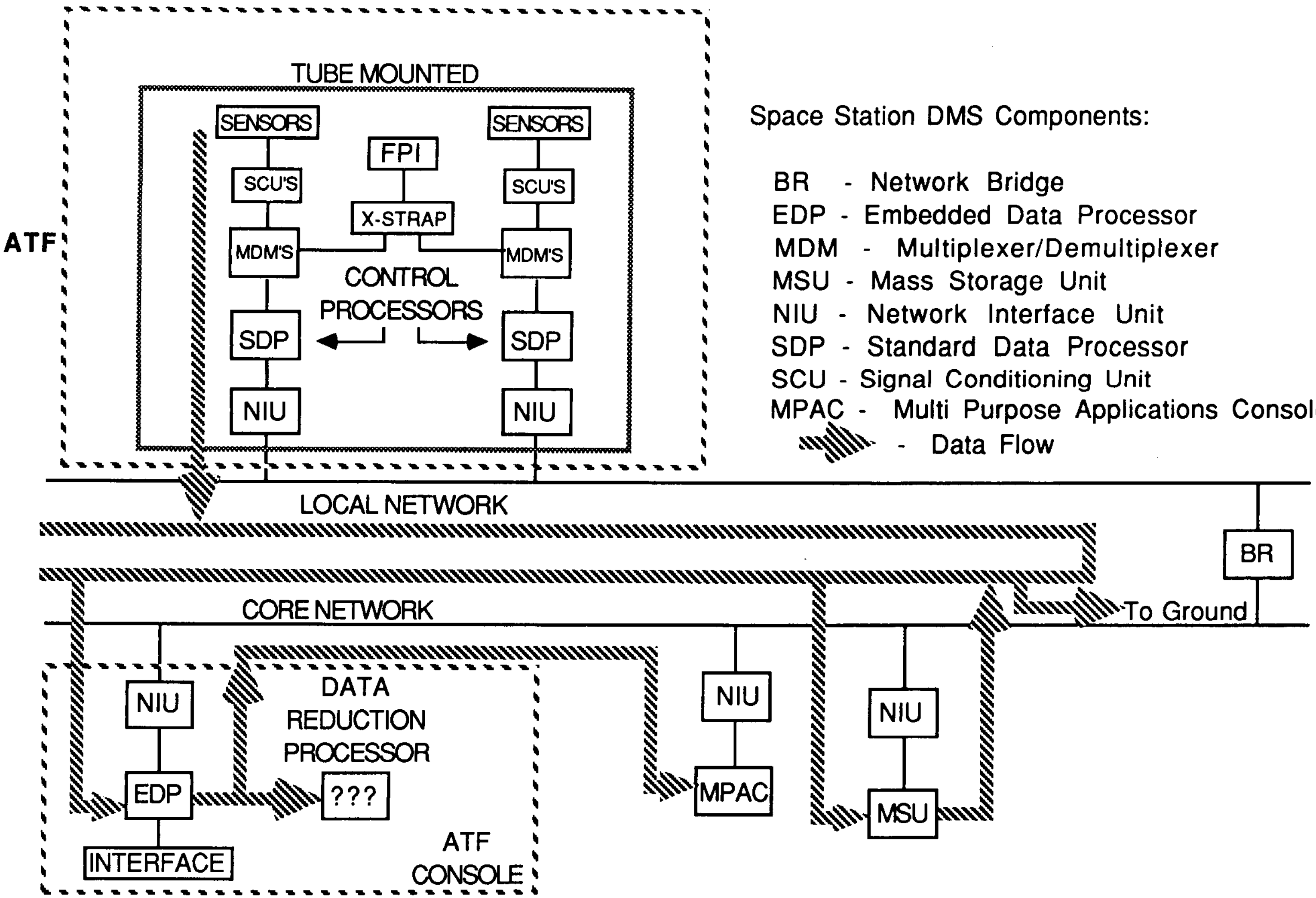
The telescope mounted equipment is string redundant with only one string operating at a time. Each string is capable of acquiring data from the sensors, monitoring the data for anomalies, responding to anomalous conditions or external commands, and formatting the data for downlink.

Internally mounted ATF equipment provides an astronaut interface for data display and command control, as well as providing contingency data reduction functions.

SS services provide network communications, data storage, and CRT/keyboard interface capabilities to the ATF.

Communication between the various ATF elements is accommodated through the SS system of networks and network bridges. This network system is expected to extend from the ATF ground-based elements to the telescope tube mounted electronics units. Not shown in this figure is the interface with the ATF pointing and control subsystem. This interface will be either directly to the pointing and control SDP, or over the local network.

COMMAND AND DATA SUBSYSTEM
SUBSYSTEM DESCRIPTION



Space Station DMS Components:

BR - Network Bridge
EDP - Embedded Data Processor
MDM - Multiplexer/Demultiplexer
MSU - Mass Storage Unit
NIU - Network Interface Unit
SDP - Standard Data Processor
SCU - Signal Conditioning Unit
MPAC - Multi Purpose Applications Console
(hatched arrow) - Data Flow

6.3.3-1 Hardware. - The CDS design makes extensive use of components which can be directly inherited from SS designs, minimizing the development and qualification costs while ensuring SS compatibility.

The ATF data are acquired at the sensors and are routed through a multiplexer to a data handling and control processor. Both the multiplexer and the data handling and control functions are performed by standard SS MDM and SDP elements. The SDP monitors the data for anomalies and formats the data for downlink. Data are transferred to the SS DMS for downlink by passing the data to a standard SS NIU. The NIU provides data packaging and network protocol functions.

The only ATF unique equipment required on the telescope for CDS functions is a relatively small signal conditioning unit to provide stable calibration currents to sensors and sensor output voltage scaling to the MDM.

ATF H/W located inside a pressurized module provide command, display, and contingency functions for the ATF. This equipment consists of a SS-developed EDP used for DMS interface tasks and engineering data processing and an as yet-unidentified processor providing contingency data reduction.

Astronaut interface with the ATF is provided through a SS MPAC which functions as a remote terminal for the EDP.

SS data-storage services are used to provide temporary storage of ATF data during contingency data-reduction processing.

COMMAND AND DATA SUBSYSTEM HARDWARE

ELEMENT	CHARACTERISTICS	ATF REQUIREMENTS	COMMENTS
MDM	11 WATTS + 2 WATTS/CARD 11 lbs + 1.6 lb/CARD 16 CARDS MAXIMUM	2 MDMs W/4 DIGITAL AND 10 ANALOG CARDS, 1 MDM W/5 DIGITAL AND 2 ANALOG CARDS *	CONFIGURABLE CARDS, 10 DIGITAL, 32 ANALOG, OR 64 BILEVEL CHANNELS
SDP	4 MIPS 4-32 MB MAIN MEMORY 50 lb 0.8 ft^3	0.5 MIPS **	ATF H/W REQUIREMENTS ARE PRELIMINARY PENDING DEFINITION OF THE S/W TASKS REQUIRED (SEE ATF S/W REQUIREMENTS)
EDP	0.5 MIPS 1 MB MAIN MEMORY 20 WATTS 5 lb 0.1 ft^3	0.2 MIPS ** 0.5 MB **	ATF H/W REQUIREMENTS ARE PRELIMINARY PENDING DEFINITION OF THE S/W TASKS REQUIRED (SEE ATF S/W REQUIREMENTS)

* MDM REQUIREMENTS HERE (THREE) ARE FOR EACH STRING.
** VALUES SUBJECT TO CHANGE UPON FURTHER DEFINITION OF S/W TASKS.

6.3.3-2 Hardware (Contd). - This page intentionally left blank.

COMMAND AND DATA SUBSYSTEM HARDWARE (CONTD)

ELEMENT	CHARACTERISTICS	ATF REQUIREMENTS	COMMENTS
NIU(S)	10 Mbps 60 WATTS 30 lb 0.6 ft^3	1.75 Mbps	PROVIDES ACCESS TO THE SS NETWORKS
SIGNAL CONDITIONING	20 WATTS 15 lb 0.3 ft^3	ATF DESIGN	PROVIDES A STABLE REFERENCE CURRENT TO SENSORS
DATA REDUCTION PROCESSOR	CANDIDATE PROCESSORS - TBD	HIGHLY DEPENDENT UPON DATA REDUCTION ALGORITHM - TBD	CONTINGENCY OPERATIONS ONLY SEE ATF S/W REQUIREMENTS

6.3.4-1 Software. - The ATF CDS requires four distinct S/W packages.

The first package is ATF peculiar and resides in the MDMs. This S/W specifies the order in which the sensor data are to be switched through the MDM. As such, it represents a map of the data format and is nearly unbranched. A different data map will be loaded for each ATF operating mode. This S/W package represents a simple and straightforward effort and is anticipated to remain static throughout the ATF mission.

Next, the SDP data handling and control processor requires S/W which is approximately 85% ATF unique. The ATF unique S/W must exercise all the operational control of the telescope as well as monitor ATF and SS data for anomalies, execute commands, and deliver the data to the SS network for distribution. The SDP will carry a S/W overhead of approximately 15%, consisting of the SS operating system, allowing a S/W interface compatible with the SS. The operating system S/W will be developed by the SS Program and will be delivered with individual units.

Inside the pressurized module, the EDP requires S/W similar to that in the SDP. This S/W must be able to extract and process the ATF engineering data, format the data for display, and generate command messages to the SDP in response to astronaut inputs. As with the SDP, this S/W will be approximately 85% unique to the ATF, with a 15% overhead consisting of the SS operating system and interface S/W. Of the ATF unique EDP S/W, approximately half is common to both the EDP and the tube mounted SDP, with only command and display tasks being unique to the EDP.

The contingency data reduction processor will require S/W 100% unique to the ATF. This S/W will consist of the data reduction algorithms necessary to reduce the data bulk by two to five orders of magnitude and will be identical to data reduction algorithms operating at the ATF Ground Operations Center.

COMMAND AND DATA SUBSYSTEM SOFTWARE

ELEMENT	CHARACTERISTICS	ATF REQUIREMENTS	COMMENTS
MDM	UNBRANCHED SENSOR SAMPLING SEQUENCE (I.E., DATA FORMAT MAP)	ON-ORBIT PROGRAMMABLE (MULTIPLE FORMATS)	STRAIGHTFORWARD S/W MINOR EFFORT
SDP	PROVIDES ATF DATA THROUGHPUT TO DOWNLINK	1.75 Mbps THROUGHPUT RATES	SPECIFIC TASK DEFINITIONS STILL TBD
	EXECUTES COMMANDS/ SEQUENCES	LOW COMMAND EXECUTION RATES	PRELIMINARY ESTIMATES USED FOR H/W REQUIREMENTS ALLOWS MARGINS
	MONITORS ENGINEERING DATA FOR ANOMALIES	SIMPLE ANOMALY RESPONSE (E.G., OBSERVATION TERMINATION)	
	PROVIDES FAULT PROTECTION RESPONSE	REALTIME OPERATION	

6.3.4-2 Software (Contd). - This page intentionally left blank.

COMMAND AND DATA SUBSYSTEM SOFTWARE (CONTD)

ELEMENT	CHARACTERISTICS	ATF REQUIREMENTS	COMMENTS
EDP	- MONITORS ENGINEERING DATA FOR ANOMALIES - PROCESSES ENGINEERING DATA - PROVIDES FOR DATA DISPLAY AND COMMAND INPUT	- SUPPORT SS MPAC INTERFACE FOR DATA DISPLAY AND COMMAND INPUT - PROVIDE INTERFACE TO DATA REDUCTION PROCESSOR - REALTIME OPERATION	- SPECIFIC TASK DEFINITIONS STILL TBD - PRELIMINARY ESTIMATES USED FOR H/W REQUIREMENTS ALLOW MARGINS
DATA REDUCTION PROCESSOR	- PROVIDES ON-BOARD DATA REDUCTION OF ATF SCIENCE DATA	- CONTINGENCY OPERATION ONLY - ITERATIVE ARITHMETIC ALGORITHM - NO COMMAND CAPABILITY - REALTIME OPERATION	- THE H/W REQUIREMENTS IMPOSED BY S/W ARE HIGHLY DEPENDENT UPON THE ALGORITHM EMPLOYED - DATA REDUCTION ALGORITHM IS STILL TBD AND SUBJECT TO TRADE-OFF STUDIES

6.3.5 Trade and Open Items. - Further work to be accomplished in the command and data area consists primarily of defining the specified tasks in greater detail.

The telescope control S/W must still be defined. A general review of operational tasks has been performed, but these tasks must be defined in terms of specific routines and estimates made of the size of the programs and the required operating speeds. This issue applies to the SDP and EDP processing tasks.

A similar task must be performed for the data-reduction S/W. Candidate data reduction algorithms are currently operating on the ground, but need to be scaled to the baseline ATF operation. Again, the size and speed requirements of this operation must be determined for at least one candidate algorithm.

Once the data-reduction algorithm has been reasonably defined, candidate processors on which to run this S/W must be identified. Because this is a contingency operation only, and is likely to be a sizable task, consideration should be given to the need of using space-qualified H/W.

Although preliminary estimates have been made as to the SS services required by the CDS, these requirements will need to be refined after the ATF S/W tasks are better understood. Changes may be required to the data storage , display, or contingency processing requirements as a result of ATF S/W constraints.

Finally, alternative CDS configurations should be investigated including such possibilities as: locating the SDP within a manned module, timesharing ATF telescope control with SS processing on SS H/W, and the possibility of supplying an ATF dedicated Mass Storage Unit.

COMMAND AND DATA SUBSYSTEM
TRADE AND OPEN ITEMS

- DEFINITION AND ESTIMATES OF ATF CONTROL S/W TASKS (SDP S/W)
- DEFINITION AND ESTIMATE OF ON-BOARD DATA-REDUCTION ALGORITHM
- IDENTIFICATION OF CANDIDATE DATA-REDUCTION PROCESSORS
- IDENTIFICATION OF REQUIRED SS DATA SERVICES
- EVALUATION OF ALTERNATIVE CDS CONFIGURATIONS

6.4 Pointing and Control Subsystem

6.4.1 Requirements/Design Accommodations. - The average observation time per star field is about 13 min; hence, slewing and reacquisition will typically occur more than 4 times/orbit, and it becomes important to minimize the impact of these functions on the operational efficiency. The ability to slew rapidly is a simple function of the torquer size, but the ability to automatically recognize and acquire a star field is a complex function of the star tracker sensitivity and field of view, telescope post-slew attitude error, and on-board computational capability. This problem is significantly alleviated for ATF by the relatively wide field of view (2.5° square) of the star tracker and the fact that there will be a predetermined and fixed number of target star fields.

The steady-state or very-low-frequency pointing accuracy specification is set by the requirement that the star images not move within the detector apertures more than a small fraction of the aperture dimension. The subtended detector aperture size will be 10 arcsec square or less.

As a first approximation, image jitter acts to increase the effective star image size. To achieve a given level of image centroiding precision, the observation time must increase by the square of the fractional increase in image size. Since the diffraction-limited image size of ATF operating in the visible portion of the spectrum is about 0.1 arcsec, the stated jitter requirement amounts to about a 10% increase in the minimum effective image size.

POINTING AND CONTROL SUBSYSTEM REQUIREMENTS/DESIGN ACCOMMODATIONS

REQUIREMENT	DESIGN	COMMENTS
SLEW 90° IN 5 MIN	COARSE POINTING SYSTEM WITH GIMBAL TORQUE MOTORS OF 30 Nm CAPABILITY	SAME TORQUE MOTORS AS IPS, AGS. MEETS REQUIREMENT WITH MARGIN
ACQUIRE AND LOCK ON TARGET IN 15 SEC	SOLID-STATE, TWO-DIMENSIONAL, ARRAY-TYPE DETECTOR IN STAR TRACKER; AUTOMATED STAR PATTERN RECOGNITION ALGORITHM	DETECTORS AND ALGORITHM DEVELOPED UNDER OTHER PROGRAMS. COMPUTER SIMULATION SHOWS ABILITY TO MEET REQUIREMENT
ACCURACY DURING 15 MIN OBSERVATION = 1 ARCSEC (DC TO 0.1 Hz)	GIMBAL TORQUE MOTORS AND VERNIER POINTING SYSTEM DRIVEN CLOSED LOOP FROM STAR TRACKER AND GYRO	SUBARCSEC LOW-FREQUENCY ACCURACY WITHIN STATE OF THE ART
JITTER LESS THAN OR EQUAL TO 0.01 ARCSEC FROM 5 TO 200 Hz	VIBRATION ISOLATION/VERNIER POINTING SYSTEM TO REDUCE RESIDUAL ROTATIONAL & LATERAL DISTURBANCES PROPAGATING THROUGH POINTING MOUNT BY 45-65 dB	MAY USE NON-CONTACTING MAGNETIC SUSPENSION OR BIPOD-TYPE ELECTRO-MECHANICAL ACTUATORS. VIBRATION ISOLATION PERFORMANCE CONTRACTOR STUDY TO BE PERFORMED

6.4.2-1 Description. - Experience with large, precision-pointed payloads operated from the Space Shuttle indicates that arcsecond-class pointing accuracy is not consistent with a design strategy employing only a single stage of control and transference of the attitude information from the platform to the payload. Therefore, the ATF design includes a two-stage pointing control system (coarse gimbals plus magnetic suspension vernier pointing) and a dedicated inertial platform on board the telescope.

POINTING AND CONTROL SUBSYSTEM DESCRIPTION

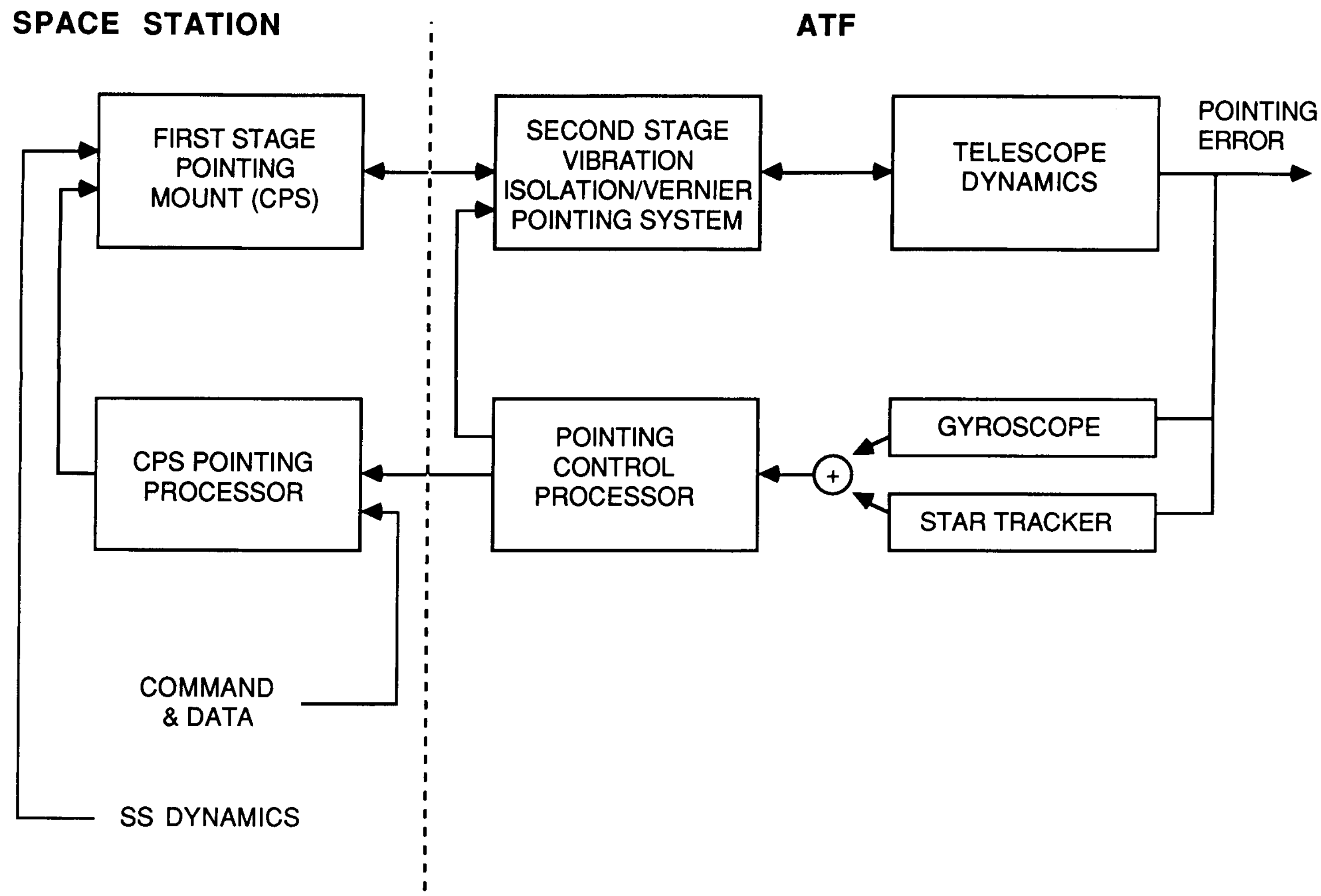
- FIRST-STAGE POINTING MOUNT TO PROVIDE:
  - LARGE-ANGLE SLEW CAPABILITY
  - THREE-AXIS POINTING TELESCOPE TO 1 ARCMIN ACCURACY AND 15 ARCSEC JITTER
- SECOND-STAGE VIBRATION ISOLATION/VERNIER POINTING SYSTEM TO PROVIDE:
  - POINTING ERROR REDUCTION TO 1.0 ARCSEC
  - IMAGE JITTER REDUCTION TO 0.01 ARCSEC (5-200 Hz)
- INERTIAL REFERENCE PLATFORM UPDATED BY STAR TRACKER TO PROVIDE POINTING REFERENCE SIGNALS OF SUBARCSEC ACCURACY

<u>6.4.2-2 Description — Functional Block Diagram</u>. - This figure shows a functional block diagram of the combined SS and ATF pointing systems.

The dashed line indicates the interface between responsibilities of the SS and the ATF projects, respectively. The arrows represent the flow of system dynamic variables between elements, which may be in the form of true physical motion or electronic signals. The arrow between the CPS block and the Vibration Isolation/Vernier Pointing System block represents a purely mechanical interface. The arrow between the pointing control processor block and the CPS pointing processor block represents a digital data interface to be physically realized using the SS local data network.

ATF SYSTEMS STUDY

POINTING AND CONTROL SUBSYSTEM FUNCTIONAL BLOCK DIAGRAM



6.4.3 Vibration Control.

6.4.3.1 Image Motion Disturbance Model: The block diagram indicates the different dynamic paths by which disturbances can contribute to apparent image motion at the Ronchi ruling. To estimate the performance required of the Vibration Isolation/Vernier Pointing System, the following assumptions were made (numbered statements refer to corresponding numbered boxes):

(1) Dominant forces are due to SS structural shaking; atmospheric drag and solar pressure are neglected.

(2) Dominant torques are bearing friction and noise; atmospheric drag and solar pressure are neglected.

(3) Isolation transfer function to be expressed as dB of attenuation; will assume separability of degrees of freedom and consider only worst, single-axis case.

(4) Assumed equivalent to second order, low-pass filter with 0.707 critical damping and bandpass of 0.1 Hz.

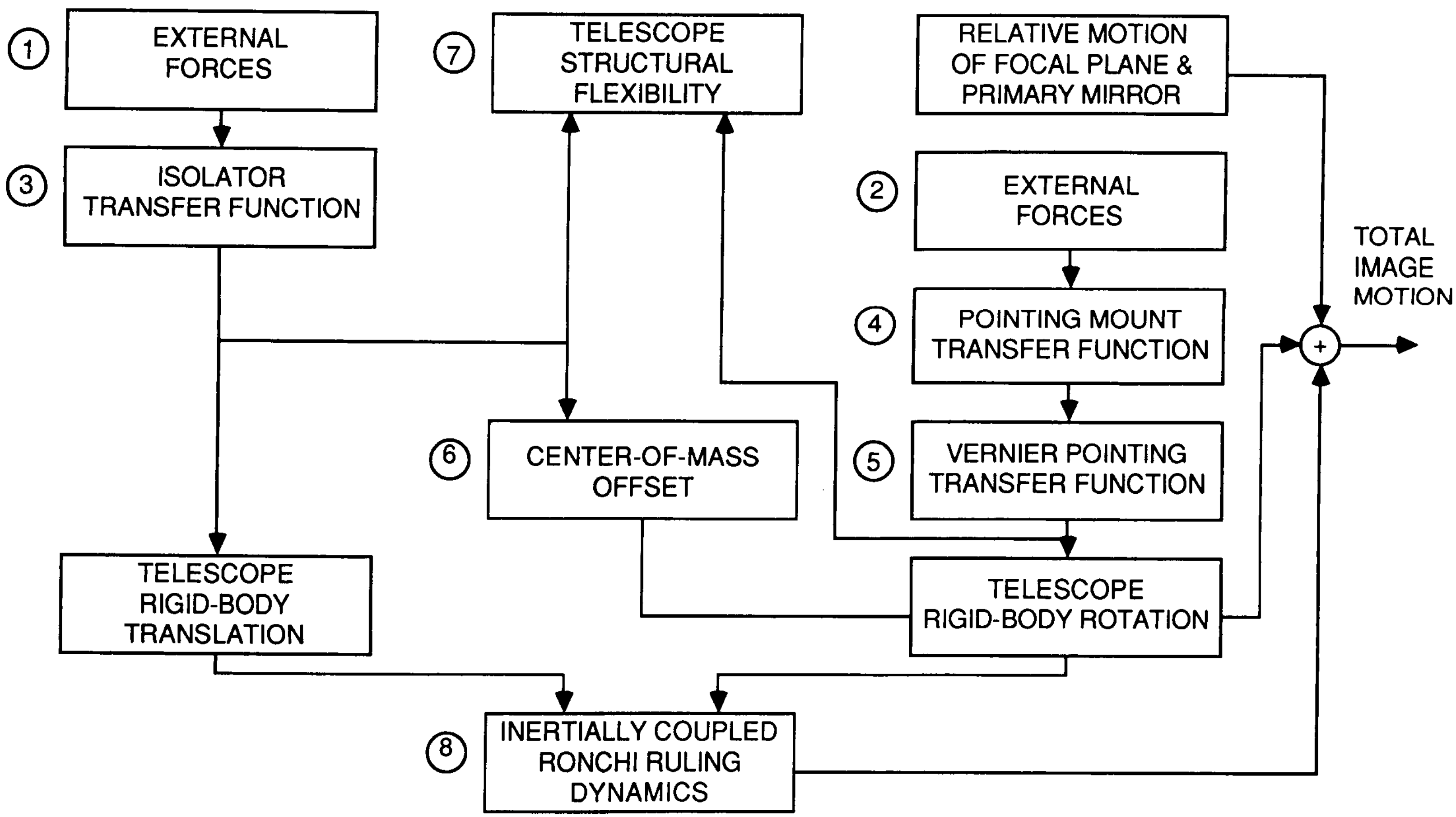
(5) Same assumptions as (3), except modified for torsional case.

(6) Error between rotation axis and true center of mass assumed to be 1 cm.

(7) Flexibility modes and frequencies from reduced-order NASTRAN model shown in section 6.1.

ATF SYSTEMS STUDY

POINTING AND CONTROL SUBSYSTEM IMAGE MOTION DISTURBANCE MODEL



6.4.3.2-1 Vibration Isolation System Performance Estimate: A detailed PSD of the vibrations entering the base of the pointing mount from the SS structure is not available at this time. For this study it was assumed that the acceleration PSD is flat from the lowest SS structure frequency (0.1 Hz) up to the highest ATF structural frequency of interest (200 Hz). An acceleration level of 10^{-2} g at 0.1 Hz corresponds to a maximum vibration amplitude at the upper-boom mounting location of about 25 cm.

POINTING AND CONTROL SUBSYSTEM — VERNIER POINTING/ VIBRATION ISOLATION SYSTEM PERFORMANCE ESTIMATE

- SPACE STATION DISTURBANCE MODEL ASSUMPTIONS:
  - ACCELERATION PSD AT POINTING MOUNT DUE TO STRUCTURAL FLEXING OF STATION IS FLAT FROM 0.1 TO 200 Hz
  - TWO DISCRETE LEVELS CONSIDERED: 10^{-2} G AND 10^{-3} G
  - VIBRATION AMPLITUDE VARIES AS $1/\omega^2$
- TELESCOPE RIGID BODY DYNAMICS:
  - RIGID BODY ROTATION DRIVEN BY OFFSET BETWEEN CENTER OF MASS AND ATTACHMENT POINT (= 1 cm)

$$J\ddot{\theta} \approx m\ddot{X}\delta$$

20-dB ATTENUATION REQUIRED FOR 1 ARCSEC ACCURACY FROM DC TO 0.1 Hz

45- TO 65-dB ATTENUATION REQUIRED FOR 0.01 ARCSEC JITTER FROM 5 TO 200 Hz

25-cm OSCILLATION AMPLITUDE IN WORST CASE

6.4.3.2-2 Vibration Isolation System Performance Estimate: This page intentionally left blank.

POINTING AND CONTROL SUBSYSTEM — VERNIER POINTING/ VIBRATION ISOLATION SYSTEM PERFORMANCE ESTIMATE

- RIGID BODY TRANSLATION ACCELERATIONS FEED DIRECTLY THROUGH TO RONCHI RULING VIA INERTIAL COUPLING
- EXTERNAL TORQUES FILTERED OUT BY BANDPASS OF POINTING MOUNT TRANSFER FUNCTION EXCEPT FOR INTERNAL SOURCES (BEARING NOISE, ETC.)
- DISTURBANCE OF RONCHI RULING THROUGH RIGID BODY COUPLING SHOWN TO BE SMALL VIA SIMULATION: $<10^{-5}$ G REGARDLESS OF GIMBAL ORIENTATION

• TELESCOPE FLEXIBILITY

- EXCITATION CAUSED BY PURE TORQUES FILTERING THROUGH POINTING MOUNT IS NEGLIGIBLE
- 45- TO 65-dB ATTENUATION REQUIRED TO MEET 0.01-ARCSEC JITTER REQUIREMENT

6.4.3.3 Image Jitter Due to Telescope Flexibility: For a linear dynamic system the response of the singular value of the transfer function represents an upper bound on the actual response of the system to a forcing function. The response function plotted shows the response of the singular value of the telescope structural model to transverse vibration applied at the telescope CG The vibration is random in phase and amplitude with an rms amplitude of 1 lbf.

The data show that a maximum of 0.067 lbf of vibration can be allowed into the telescope structure without exceeding the 0.01-arcsec image jitter specification. Since the proportionality constant between force and acceleration is the mass of the telescope, this amounts to an allowable acceleration level of the telescope of 6.0×10^{-6} G. Therefore, if the vibratory acceleration level on the SS is as large as 10^{-2} G, then as much as 65 dB of attenuation is required of the vibration isolator.

POINTING AND CONTROL SUBSYSTEM
IMAGE JITTER DUE TO TELESCOPE FLEXIBILITY

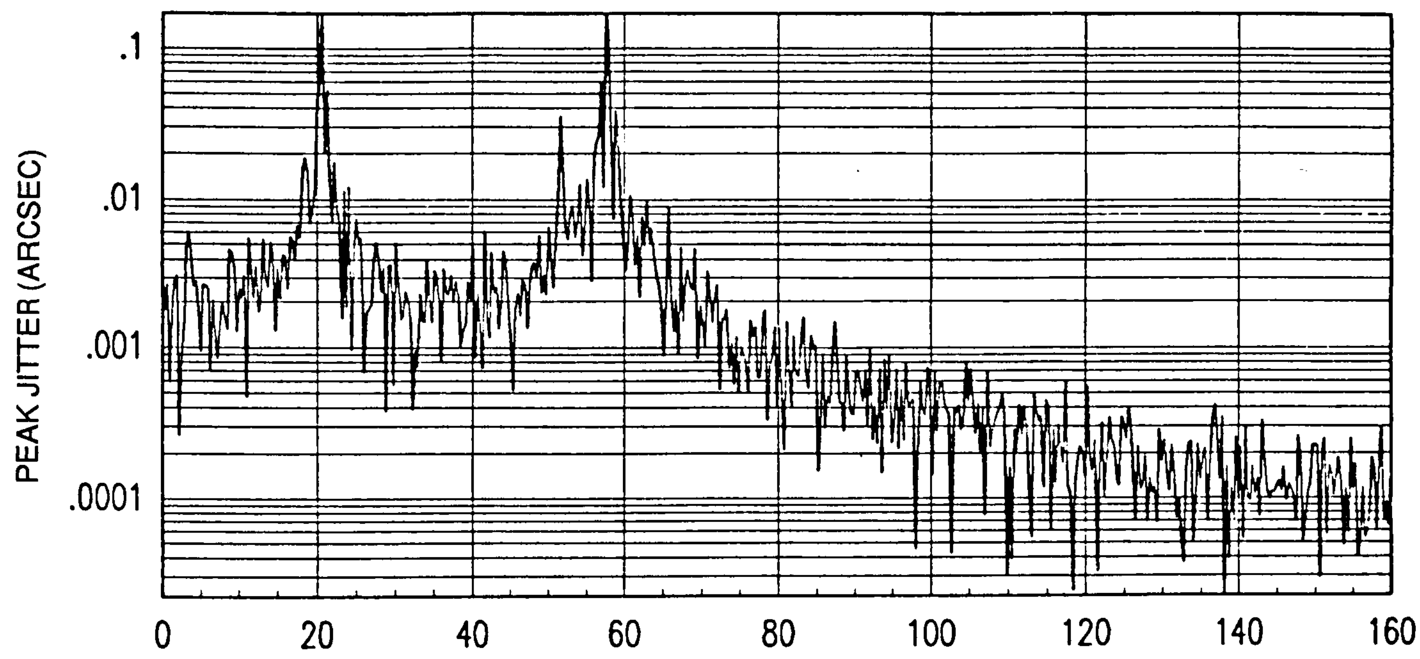
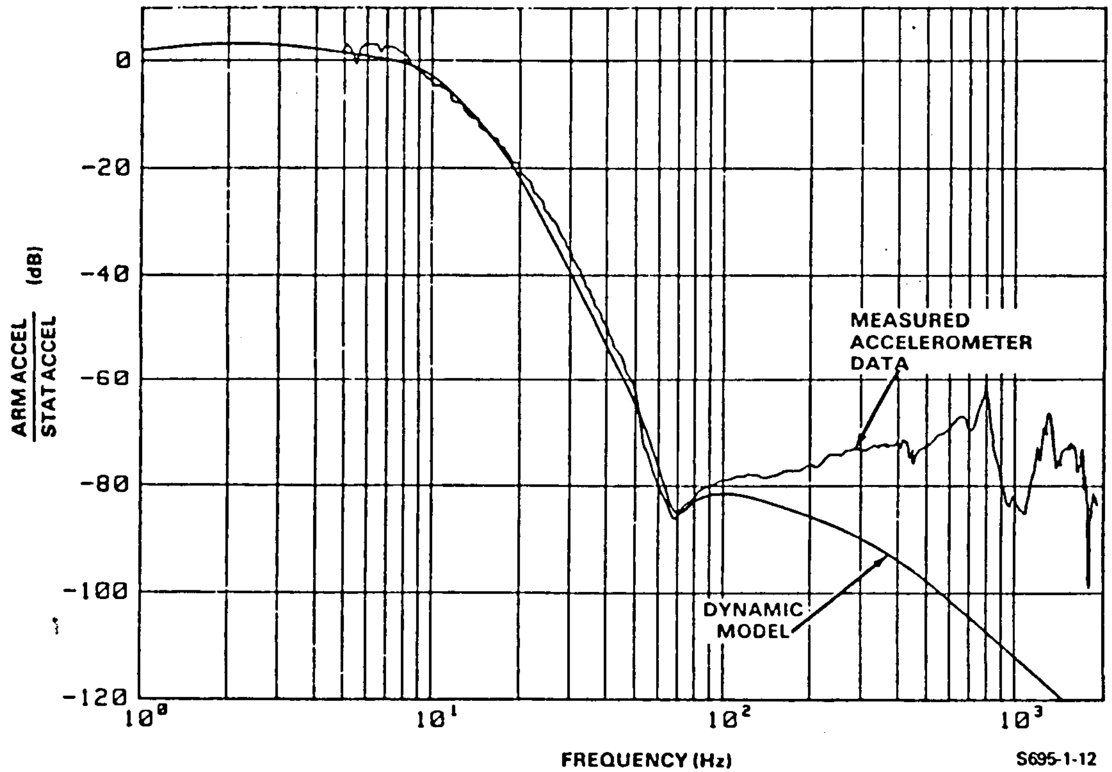


IMAGE MOTION CAUSED BY RANDOM DISTURBANCE OF UNIT RMS INTENSITY (lbf)

6.4.3.4 Magnetic Suspension Performance: The frequency response plot shows the correspondence between laboratory measured data and the dynamic model prediction of a representative magnetic suspension system. The laboratory data were taken from a single-axis experiment conducted with an air-bearing vehicle floated on a granite surface plate. There appear to be no fundamental technological problems associated with moving the breakpoint of the attenuation transfer function to the lower frequency required by the ATF. From these results it appears the worst case 65 dB of isolation required for ATF can be achieved.

POINTING AND CONTROL SUBSYSTEM
MAGNETIC SUSPENSION PERFORMANCE



Comparison of Isolation Characteristics Between
Measured Accelerometer Response
and Dynamic Model Prediction

6.4.4 Hardware Description Overview. - This figure shows the origin of the major H/W elements in the pointing and control subsystem. Only the Vibration Isolation/Vernier Pointing System will have to be developed specifically for the ATF. All other elements are either existing designs with little or no modification, or will be developed by the SS Program. Further, the technology required for the Vibration Isolation/Vernier Pointing System has been demonstrated and is continuing to be refined within both NASA and the Department of Defense (DOD).

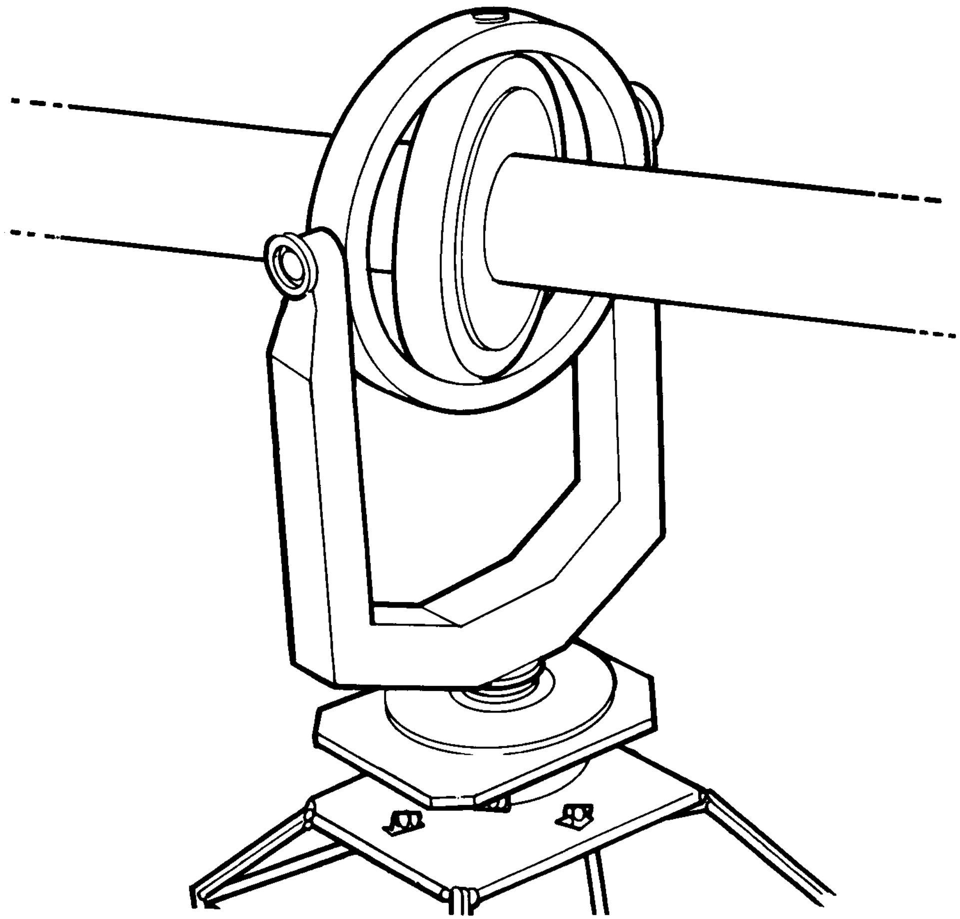
POINTING AND CONTROL SUBSYSTEM HARDWARE DESCRIPTION OVERVIEW

- COARSE POINTING SYSTEM TO BE DESIGNED BY SS PROGRAM
- VIBRATION ISOLATION/VERNIER POINTING SYSTEM TO BE CUSTOM DESIGNED FOR ATF PROJECT (COMPONENT TECHNOLOGY DEMONSTRATED FOR ASPS, SOT PROJECTS)
- DRIRU-11 GYRO IN SERIES PRODUCTION (PERFORMANCE MAY BE TAILORED FOR INDIVIDUAL APPLICATIONS)
- ASTROS STAR TRACKER DESIGN AVAILABLE FOR SERIES PRODUCTION (WILL REQUIRE ALTERNATE CCD)
- STANDARD DATA PROCESSOR TO BE DESIGNED BY SS PROGRAM
- SUN SENSOR TO BE DESIGNED FOR ATF PROJECT (QUAD-CELL DETECTOR TECHNOLOGY DEMONSTRATED ON NUMEROUS PROJECTS)

6.4.4.1-1 Hardware Description: The final configuration of the CPS is not yet defined. The drawing shows one of several configurations under consideration. The inside diameter of the innermost mounting ring is assumed to be 4.0 m and the swingthrough radius of the yoke is assumed to be 6.0 m. This particular configuration has the characteristic that if the telescope tube is too long to swing through the yoke, then it will pass through the condition of "gimbal lock" for target tracks longer than about 40°. During gimbal lock, the CPS would lose its ability to provide arcminute-level pointing and the ATF would have to compensate for this with increased dynamic range in the vernier pointing system (other configurations being considered do not suffer from this effect).

POINTING AND CONTROL SUBSYSTEM HARDWARE DESCRIPTION

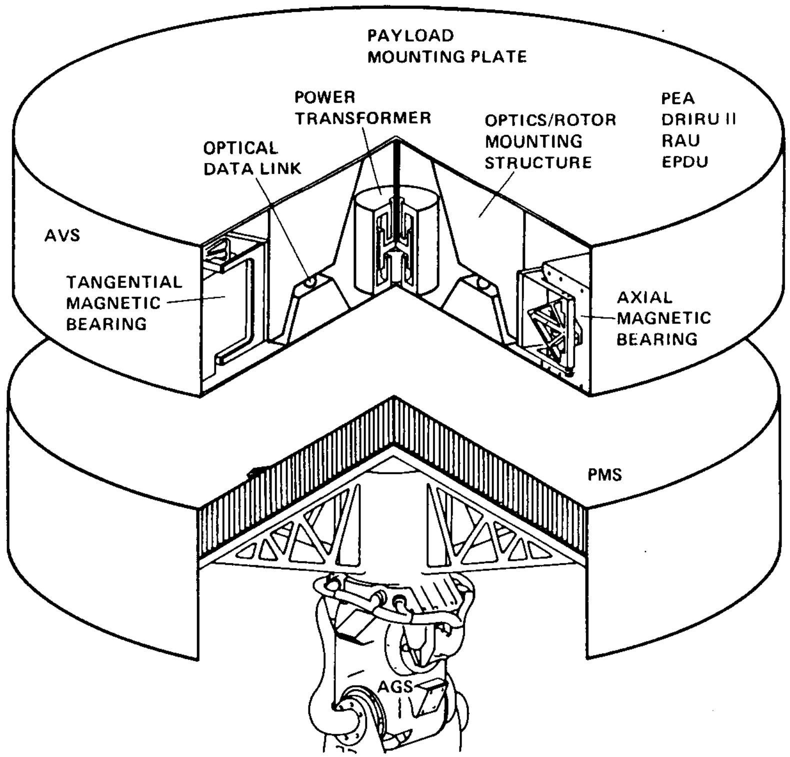
- FIRST STAGE POINTING MOUNT:
  - SPACE STATION PROJECT-DESIGNED COARSE POINTING SYSTEM



6.4.4.1-2 Hardware Description (Contd): The Annular Suspension and Pointing System (ASPS) is an example of a combined Vibration Isolation/Vernier Pointing System using magnetic suspension actuators. This H/W has not flown in space, but is fully flight qualifiable. In addition to the magnetic actuators, this design uses a noncontacting transformer for power transmission and a modulated light beam for data transmission. During operation the payload has no physical contact with the gimbal system. This design is for an end-mounted payload; the components would have to be rearranged to accommodate ATF in a CG-mounted configuration.

POINTING AND CONTROL SUBSYSTEM HARDWARE DESCRIPTION (CONTD)

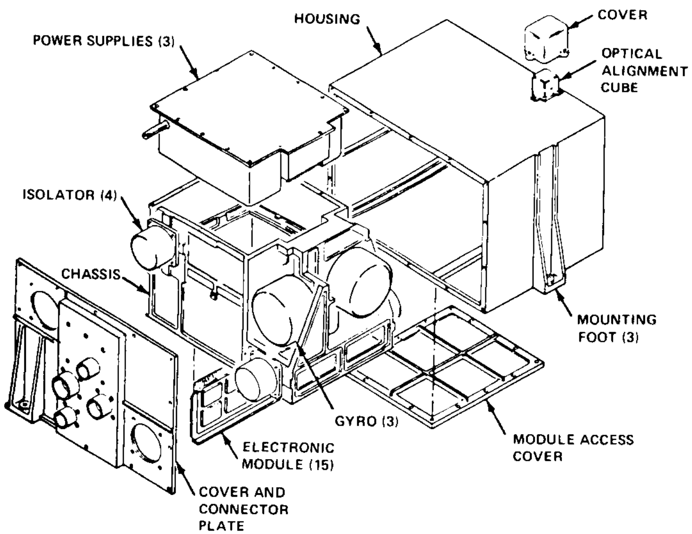
- SECOND STAGE POINTING/ISOLATION SYSTEM:
  - MAGNETIC SUSPENSION TECHNOLOGY



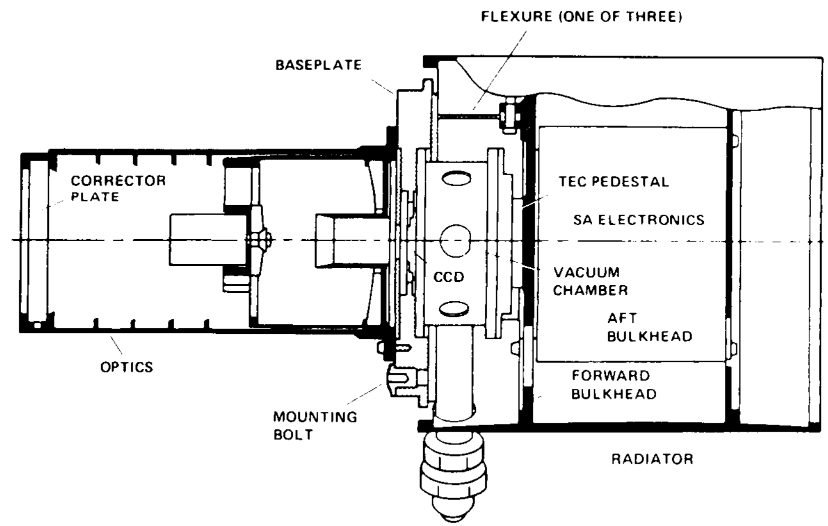
6.4.4.1-3 Hardware Description (Contd): The output signals from a star tracker and a gyroscope are combined in a Kalman filter implemented in the pointing control processor to produce a high-rate, real-time estimate of the pointing direction of the telescope. The DRIRU-II 3-axis gyro has been well proven on many free-flyer spacecraft flights and the ASTRO star tracker was qualified to fly on a Spacelab mission. These components are expected to produce pointing reference signals accurate to better than 1 arcsec.

POINTING AND CONTROL SUBSYSTEM HARDWARE DESCRIPTION (CONTD)

NASA STANDARD HIGH-PERFORMANCE GYRO



SOLID-STATE ARRAY-TYPE STAR TRACKER



6.4.5 Trade and Open Issues. - The current ATF system conceptual design uses a CPS to be developed and qualified by the SS Program. Not all of the possible CPS designs would be equally capable of performing the ATF mission; some may not be capable of performing it at all. In addition, it is not clear whether the CPS will be available for the 20-year duration of the ATF mission.

The design in which the vibration isolator is located within the innermost CPS yoke was chosen on the basis of being most likely to have a positive performance margin. When the Power Spectral Density (PSD) of station disturbances and the gimbal system mechanical design are both defined more quantitatively, it may become possible to design other configurations that are more cost-effective.

POINTING AND CONTROL SUBSYSTEM TRADE AND OPEN ISSUES

- PERFORMANCE AND AVAILABILITY OF CPS
- SYSTEM IMPACT OF VIBRATION ISOLATION SYSTEM LOCATION
- PERFORMANCE OF VIBRATION ISOLATOR
- THE PSD OF SS DISTURBANCES
- INTERFACE BETWEEN CPS AND PAYLOAD

6.5 Power and Harness Subsystem

6.5.1 Power Requirements/Accommodations. - Basic power for ATF operation will be supplied by the SS. Therefore, the requirements on the Power and Harness Subsystem are limited to regulation, unit ON/OFF power switching, current limiting, over/under-voltage control, and distribution. All of the requirements can be accommodated by standard spacecraft design techniques.

POWER AND HARNESS SUBSYSTEM REQUIREMENTS/DESIGN ACCOMMODATION

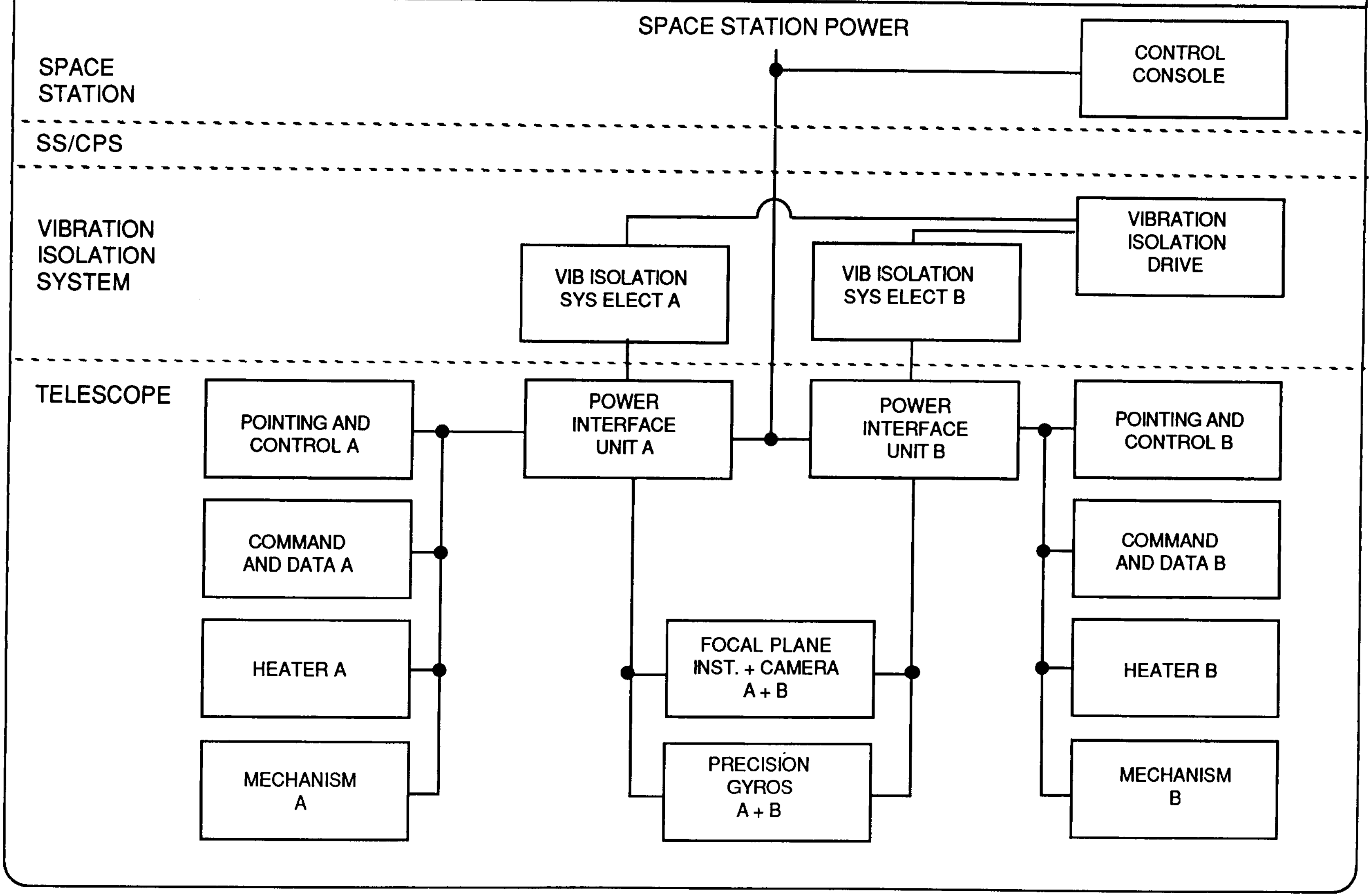
REQUIREMENTS	DESIGN	COMMENTS
• REGULATED POWER FOR ELECTRONICS	- USES DC POWER FROM SS - USES DC-DC ISOLATION - REGULATION (0.1%, 1.0%, 5%) - LOW IMPEDANCE	- SEPARATE POWER SUPPLIES FOR CRITICAL UNITS (MINIMIZE CROSS TALK) - STANDARD AND SPECIAL VOLTAGES
• UNREGULATED POWER FOR HEATERS, MOTORS	- USES SS DC LINE SOURCES - REGULATION (10%)	- RULING DRIVE MOTORS WILL HAVE 1.0% REGULATION
• POWER SWITCHING	- ON/OFF RELAYS LOCATED IN POWER INTERFACE UNIT - ADDITIONAL ONM/OFF RELAYS IN UNIT BOXES	- FOR POWER ON/OFF - FOR TROUBLESHOOTING
• CURRENT LIMITING AND OVER-VOLTAGE PROTECTION	- PROTECTION OF HARNESS AND EQUIPMENT	- COMMANDABLE OVERRIDE
• DISTRIBUTION	- STANDARD HARNESS - SEPARATE POWER BUNDLE - TWISTED PAIRS - WIRES USED FOR POWER RETURN	- FLIGHT APPLICATION (FLEXIBILITY, SERVICE LOOP, UNIQUE KEYING OF CONNECTORS)

6.5.2 Power Subsystem Block Diagram. - The power subsystem will have dual strings of components, consistent with the overall ATF design philosophy described in section 4.9; i.e., independent string redundancy is employed for simplicity, reliability, and ease of maintenance. Basic power is supplied by the SS to the ATF console in one of the pressurized modules and to the telescope across the pointing mount. The ATF strawman design assumes the station will supply DC power. However, AC power could be accepted with little impact to the ATF system.

Figure 6.5.2 shows a block diagram of the power subsystem indicating the redundant approach. For units which are not redundant (gyros and FPI) input circuits will be designed to prevent a short on one side from effecting the other.

ATF SYSTEMS STUDY

POWER AND HARNESS SUBSYSTEM
POWER SUBSYSTEM BLOCK DIAGRAM



6.5.3 Operating Modes. - The ATF will have two basic power modes. Under normal conditions the facility will be in the operating mode for which the average power level is 1408 W with a peak of 2503 W. When the facility is off, 1145 W are required for replacement heaters for thermal control. These estimates were derived from past flight H/W program experience and compare favorably with estimates for other orbiting observatories such as SIRTF and AXAF.

Figures 6.5.4, 6.5.5, and 6.5.6 provide a detailed breakdown of the power estimate by unit. Figures 6.5.4 and 6.5.5 also show the power quality requirements for each unit. It is assumed that SS power can be used for heaters without additional conditioning.

POWER AND HARNESS SUBSYSTEM
POWER SUBSYSTEM — VARIOUS MODES AND BUDGETS

C-Y

- NORMAL OPERATING MODE
- POWER OFF MODE

6.5.3.1-1 Power — Normal Operating Mode: This page intentionally left blank.

POWER AND HARNESS SUBSYSTEM
POWER — NORMAL OPERATING MODE

ELEMENT	POWER (W) AVG	POWER (W) PEAK	COMMENTS
• POINTING AND CONTROL			
SUN SENSOR	10	10	REGULATED ≤1%
STAR TRACKER	80	80	REGULATED ≤1%
PRECISION GYROS	30	30	REGULATED ≤1%
POINTING AND CONTROL PROCESSOR	100	100	REGULATED ≤1%
ROLL CONTROL ELECTRONICS	20	20	REGULATED ≤1%
ROLL CONTROL MOTOR	0*	200	SS DC LINE POWER
VIBRATION ISOL/FINE POINTING	420	840	SS DC LINE POWER
SUBTOTAL	660	1280	
• FOCAL PLANE INSTRUMENT			
DETECTORS/ELECTRONICS	100	100	REGULATED ≤1%
DRIVE MOTORS	0*	400	REGULATED ≤1%
VISUAL IMAGER	0*	30	REGULATED ≤1%
SUBTOTAL	100	530	
• COMMAND AND DATA			
NETWORK INTERFACE UNIT	60	60	REGULATED ≤1%
STANDARD DATA PROCESSOR	100	100	REGULATED ≤1%
MULTIPLEXER/DEMULTIPLEXER	97	97	REGULATED ≤1%
SIGNAL CONDITIONING UNIT	40	40	REGULATED ≤1%
SUBTOTAL	297	297	

6.5.3.1-2 Power — Normal Operating Mode (Contd): This page intentionally left blank.

POWER AND HARNESS SUBSYSTEM
POWER — NORMAL OPERATING MODE (CONTD)

ELEMENT	POWER (W) AVG	POWER (W) PEAK	COMMENTS
• POWER			
CONVERTER AND SWITCHES	100	100	REGULATED ≤1%
• MECHANISMS/OPTICS			
APERTURE DOOR	5	10	SS DC LINE POWER
MIRROR CONTROL SYSTEM	0*	40	REGULATED ≤1%
RONCHI RULING DRIVE	50	50	REGULATED ≤1%
MIRROR HEATER	96	96	SS DC LINE POWER
SUBTOTAL	151	196	
• CONTROL CONSOLE			
ELECTRONICS	100	100	REGULATED ≤1%
TOTAL	1408	2503	

* SHORT DUTY CYCLE SO AVERAGE POWER IS SMALL; FUNCTION USED PRIMARILY FOR SETUP, CALIBRATION, OR DIAGNOSTICS.

6.5.3.2 Power — Power Off Mode: This page intentionally left blank.

POWER AND HARNESS SUBSYSTEM
POWER — POWER OFF MODE

	POWER (W)
• REPLACEMENT HEATER POWER (THERMAL CONTROL)	
- AFT-END ELECTRONICS	407
- FORWARD-END ELECTRONICS (INCLUDES FPI)	268
- VIBRATION ISOLATION SYSTEM	374
• MIRROR HEATER	96
TOTAL	1145

6.5.4 Power Subsytem Hardware. - The H/W for this subsystem consists of the Power Interface Unit electronics boxes (one box for each redundant system string) and the harness.

The electronics will incorporate standard SS boards for DC-DC conversion and regulation. The remainder of the circuits will be standard types used in spacecraft systems.

The harness will be a custom design for ATF using standard materials and processes for spacecraft use. Space Station design connectors developed for EVA and/or robotic connect/disconnect will be used.

POWER AND HARNESS SUBSYSTEM
POWER SUBSYSTEM — HARDWARE

- POWER INTERFACE UNIT
  - STANDARD SS BOARDS

    DC-DC CONVERTERS
    REGULATED $\leq$ 1%
    SELECTED STANDARD VOLTAGES
    SELECTED WATTAGES
    PLUG-IN BOARDS

  - CUSTOM CIRCUITS

    NONSTANDARD VOLTAGES
    ON/OFF SWITCHING
    REGULATION
    CURRENT LIMITING

- HARNESS
  - CUSTOM HARNESS

    STANDARD FLIGHT TECHNIQUE
    SEPARATE RUN FOR HIGH-POWER
    WIRE USED FOR POWER RETURN

  - SS CONNECTOR DESIGN

    NEEDED FOR EASE OF DISCONNECT

6.5.5 Power Subsystem — Trades and Open Issues. - This page intentionally left blank.

POWER AND HARNESS SUBSYSTEM
POWER SUBSYSTEM — TRADE AND OPEN ISSUES

- EMC CONCERNS FOR VIBRATION ISOLATION POWER SUPPLY

7.0 SPACE STATION AND STS INTERFACES

7.1 Space Station Interfaces

7.1.1 Mechanical. - The ATF telescope requires that the facility be able to support four mechanical interfaces with the SS.

During normal operations, the main telescope tube will reside on the upper science boom. The mechanical interface to the station at this location is through the CPS. The ATF telescope will be mounted to the CPS at its center of mass, near the geometric center of the tube, and will require on-orbit assembly.

For assembly and installation of the ATF, the facility provides the mechanical attach points on each subassembly necessary to manipulate and align the pieces. These attach points will be designed to accommodate an interface with either the Mobile Servicing Center (MSC) or astronaut EVA.

Additionally, each On-orbit Replaceable Unit (ORU) will provide MSC and astronaut compatible attach points for use during repair activities.

The ATF telescope will provide SS Service Bay Attach points for use in the event that the Service Bay is operational and desirable for either ATF assembly or repair.

The ATF control console will be mounted inside a manned module and will be designed for standard electronics rack mounting.

SPACE STATION INTERFACES
MECHANICAL

LOCATION	REQUIREMENT
UPPER BOOM	DURING OPERATION, THE ATF TELESCOPE WILL BE MECHANICALLY MOUNTED ON AN SS SUPPLIED CPS ON THE UPPER SCIENCE BOOM
PRESSURIZED MODULE	THE ATF CONTROL CONSOLE WILL BE RACK MOUNTED IN ONE OF THE MANNED MODULES
SERVICE BAY	THE ATF WILL MECHANICALLY INTERFACE WITH THE SS SERVICE BAY DURING ON ORBIT ASSEMBLY
MOBILE SERVICING CENTER	THE SS MSC WILL MECHANICALLY INTERFACE WITH THE ATF, BOTH AS A WHOLE, AND WITH EACH REPLACABLE UNIT INDEPENDENTLY

7.1.2 Command and Data. - All ATF information, whether data or commands, will be carried over the SS DMS network system. All ATF command and data interfaces to this network system will use standard SS DMS H/W (Network Interface Unit) and S/W (Network Operating System).

The baseline ATF concept calls for supporting a command and data interface at three different locations on the SS: at the telescope, the internal control panel, and in the Service Bay should that facility be available and desirable. It is anticipated that the SS DMS network will extend across the pointing mount gimbals and will be available for ATF interface at the telescope tube.

All handling of data and commands after they have been placed on the network is the responsibility of the SS Information System and is transparent to the ATF.

SPACE STATION INTERFACES
COMMAND AND DATA

LOCATION	REQUIREMENT
UPPER BOOM	THE ATF WILL SUPPORT AN INTERFACE TO THE STANDARD SS PAYLOAD INTERFACE ADAPTER (PROVIDING COMMAND AND DATA INTERFACE WITH THE SPACE STATION DMS LOCAL AREA NETWORK ON THE UPPER SCIENCE BOOM) USING SS DERIVED H/W AND S/W TO BE MOUNTED ON THE ATF TELESCOPE
PRESSURIZED MODULE	THE ATF WILL SUPPORT A COMMAND AND DATA INTERFACE WITH THE SS DMS CORE NETWORK IN ONE OF THE MANNED MODULES USING SS DERIVED H/W AND S/W
SERVICE BAY	THE ATF COMMAND AND DATA INTERFACE WHILE IN THE SERVICE BAY WILL BE IDENTICAL TO THAT ON THE UPPER BOOM (USE OF STANDARD SS PAYLOAD INTERFACE ADAPTER), PROVIDED FOR THE PURPOSE OF ON-ORBIT ASSEMBLY AND CHECKOUT

7.1.3 Pointing and Control. - Coarse pointing of the ATF telescope will be the responsibility of the CPS. The ATF will supply target coordinates to the CPS via the SS DMS.

The ATF will also support a hardline interface directly to the CPS. This interface will be unidirectional, and will consist of a pointing error signal derived from ATF mounted star trackers and gyroscopes. This signal is provided to the CPS to enhance its pointing capabilities. Any additional pointing capabilities required by the ATF will be self provided and will not require a CPS interface.

SPACE STATION INTERFACES POINTING AND CONTROL

LOCATION	REQUIREMENT
UPPER BOOM	THE ATF WILL SUPPORT A POINTING ERROR SIGNAL INTERFACE TO THE SS CPS FOR FINE-POINTING ADJUSTMENTS

7.1.4 Power. - The ATF will provide standard payload power interface connections at the Vibration Isolation/Vernier Pointing Subsystem using SS-developed interface electronics. From this point, power conversion and distribution will be the responsibility of the ATF.

It is anticipated that this standard power interface would be compatible with the Service Bay should that facility be available and desirable for ATF assembly or repair.

Within the manned modules, the ATF control console will be designed with a single power interface, using SS-developed interface electronics and standard electronics rack power interface connectors.

SPACE STATION INTERFACES
POWER

LOCATION	REQUIREMENT
UPPER BOOM	THE ATF WILL PROVIDE A SINGLE POWER INTERFACE FOR ALL TELESCOPE MOUNTED EQUIPMENT AND A SEPARATE INTERFACE FOR THE VIBRATION ISOLATION/VERNIER POINTING SYSTEM. BOTH INTERFACES WILL USE H/W SUPPORTING AN INTERFACE TO THE STANDARD SS PAYLOAD INTERFACE ADAPTER
PRESSURIZED MODULE	THE ATF WILL PROVIDE A SINGLE POWER INTERFACE FOR THE CONTROL CONSOLE
SERVICE BAY	THE ATF POWER INTERFACE WHILE IN THE SERVICE BAY WILL BE IDENTICAL TO THAT ON THE UPPER BOOM (USE OF STANDARD SS PAYLOAD INTERFACE ADAPTER)

7.1.5 Thermal. - The ATF baseline requires no thermal interface to the SS and depends entirely on passive cooling.

SPACE STATION INTERFACES
THERMAL

<u>REQUIREMENTS</u>

NONE

7.2 STS Interfaces

The ATF will provide Airborne Support Equipment (ASE) for mechanically interfacing the facility to the shuttle.

The ATF requirements for an STS electrical interface consists only of a power interface to supply power to passive resistance heaters, enabling ATF components to be maintained within acceptable temperature ranges.

STS INTERFACES

MECHANICAL	THE ATF WILL PROVIDE A LAUNCH CONFIGURATION PACKAGING, INTERFACING TO THE STS THROUGH THE ATF ASE, COMPLIANT WITH ALL STS SAFETY REQUIREMENTS
ELECTRICAL	INTERFACE LIMITED TO POWER FOR RESISTANCE HEATERS. ALL OTHER SYSTEMS INACTIVE WHILE IN STS.

8.0 MISSION ANALYSIS

8.1 Observation Requirements

This analysis investigated the capability of the ATF to perform astrometric measurements of a selected star-field and determined appropriate telescope aiming strategies and viewing time summaries for use by the ATF while mounted on the SS. Viewing time (or photon integration) is accumulated more or less uniformly on all the selected stars.

MISSION ANALYSIS
OBSERVATION REQUIREMENTS

- PERFORM ASTROMETRIC MEASUREMENTS ON AT LEAST 100 TARGET STARS OF VISUAL MAGNITUDES -1.5 TO +13.5 WITH ASSOCIATED REFERENCE STARS DOWN TO +15 MAGNITUDE
- PREFER CAPABILITY OF VIEWING IN ALL DECLINATIONS
- PROVIDE 20 TO 50 OBSERVATIONS OF EACH STAR OVER A 20-YEAR PERIOD WITH EMPHASIS ON EVERY 3 MON
- HAVE CONTINUOUS TRACKING PERIODS OF AT LEAST 7 MIN
- OBTAIN OBSERVATIONS ON ALL STARS SOMEWHAT UNIFORMLY

8.2 Baseline Mission Analysis

8.2.1 Description of Star-field. - For this preliminary design study, a field of stars was chosen which was representative of available stars of interest so that a simulation of the telescope facility tracking and aiming capability could be analyzed. The stars were chosen to be somewhat evenly spaced over the celestial sphere and have the characteristics shown in the adjacent chart.

MISSION ANALYSIS
DESCRIPTION OF STAR-FIELD

- TOTAL NUMBER OF STARS: 127
- APPROXIMATELY EQUALLY SPACED OVER CELESTIAL SPHERE IN 114 REGIONS
- TWELVE REGIONS HAVE BINARY STARS
- DISTRIBUTION OF STAR TYPES INCLUDES:

  2 GIANTS
  3 SUBDWARFS
  7 WHITE DWARFS
  1 B
  11 A
  16 F
  32 G
  23 K
  32 M

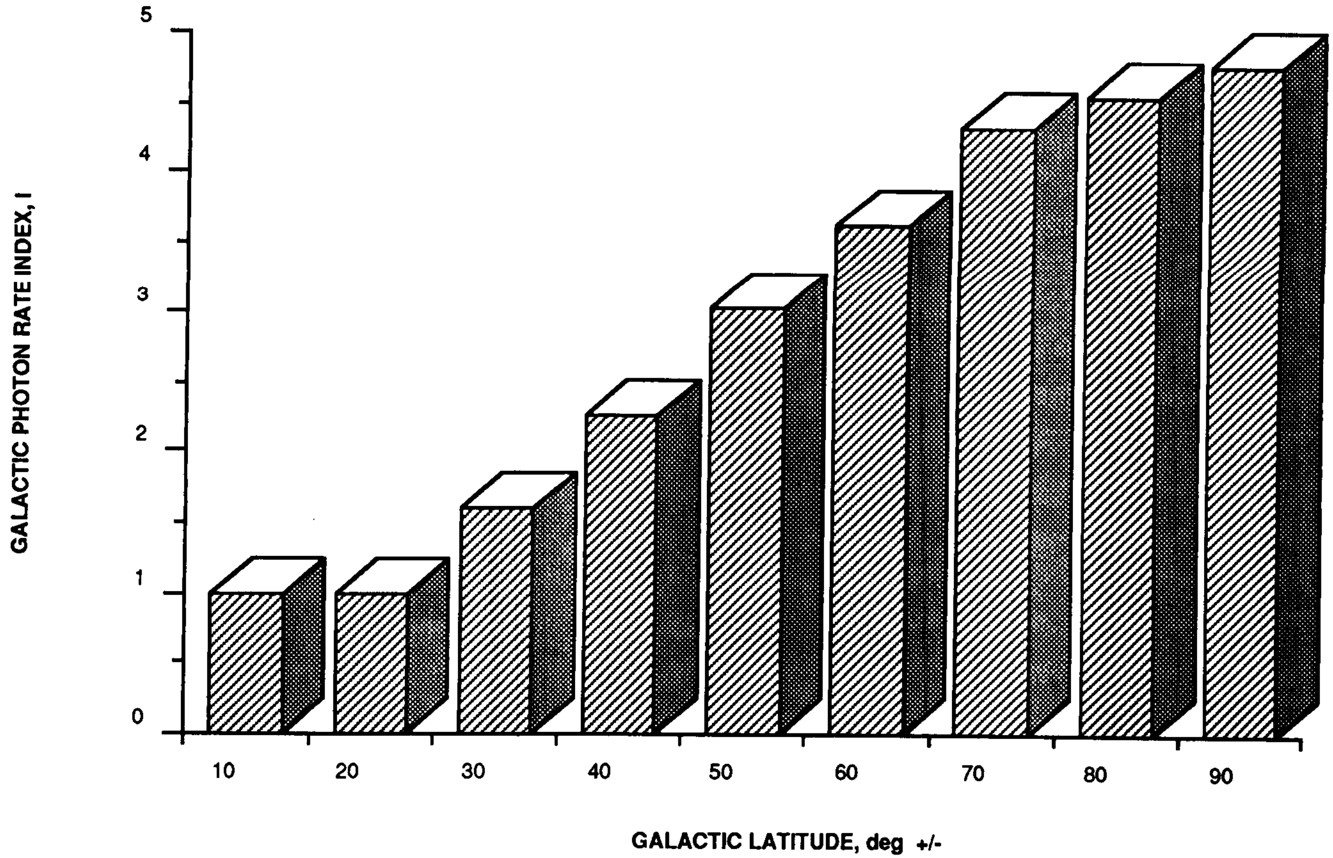
- TOTAL OF NEAR-SOLAR TYPE = 56%

8.2.2 Galactic Latitude Dependency. - Targets and their associated reference frames are assumed to have decreasing brightness with increasing galactic latitude as described in section 3.5.

To aggregate equal photon integration for each target, the required viewing time is increased according to the star's latitude. This increase is given by the parameter called "galactic photon rate index I, (defined as the photon rate at the galactic equator divided by the photon rate at the latitude of the target star) and is shown in the adjacent chart as a function of galactic latitude. Thus stars at higher latitudes are viewed for longer periods of time resulting in approximately the same accumulation of photons as those stars near the galactic equator.

MISSION ANALYSIS
GALACTIC LATITUDE DEPENDENCY

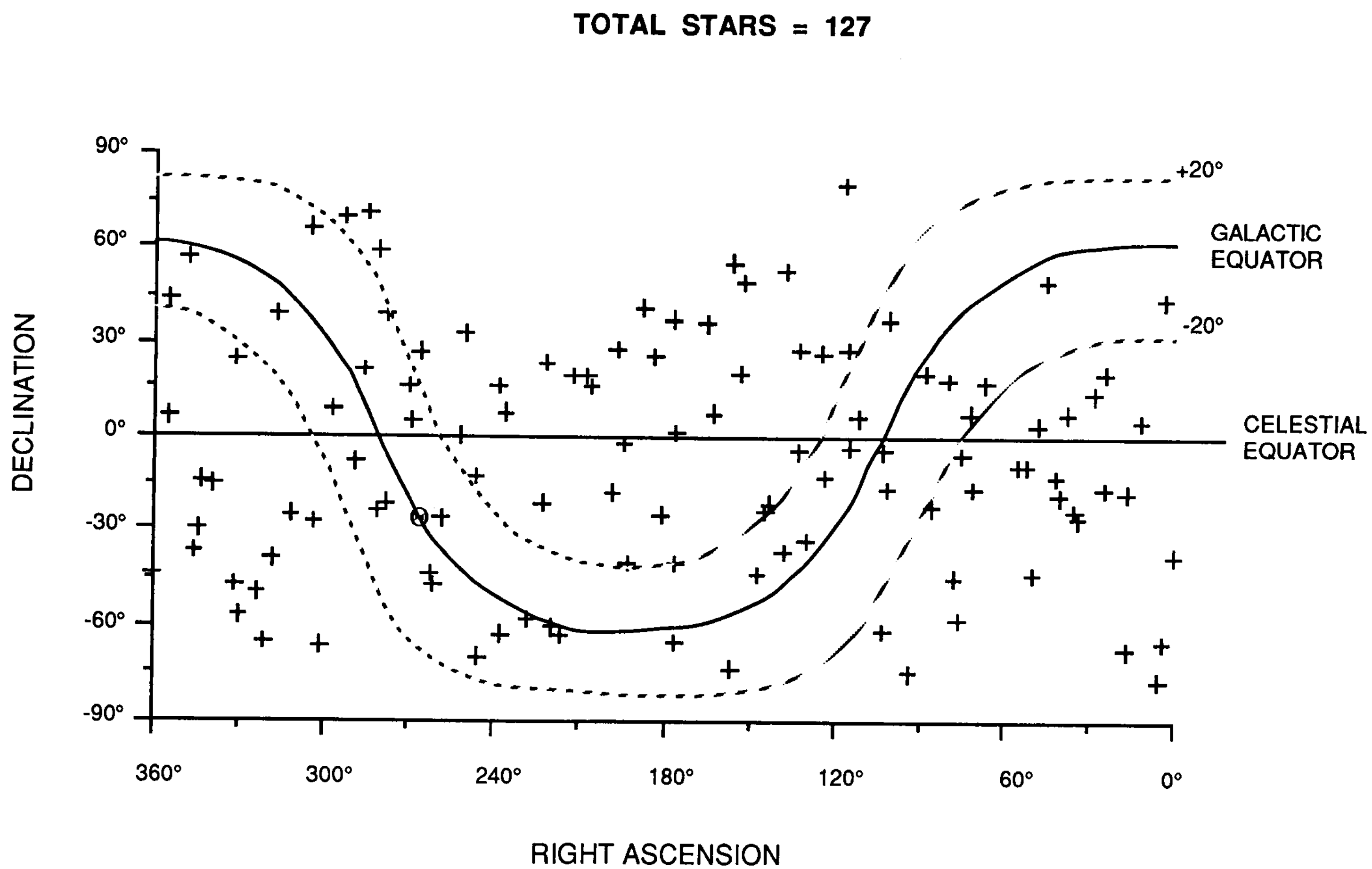
GALACTIC PHOTON RATE INDEX VERSUS LATITUDE



8.2.3 Location of Stars. - Shown on the adjacent chart is the location of each of the 127 stars chosen for this analysis. Because this is a two-dimensional projection of the celestial sphere, there appears to be fewer stars at the higher declinations than really exist. Also shown as a dashed line is the galactic equator and a faint dashed line depicting the region 20° above and below the galactic equator. The galactic center is shown by the "X" at a right ascension of 266° and declination of -30°.

ATF SYSTEMS STUDY

MISSION ANALYSIS
LOCATION OF STARS



8.2.4 Pointing Constraints. - Certain constraints, scientific requirements, and system overrides are an integral part of the computer simulation developed for this study. To protect the aperture from impact with space-borne particles, debris, ions, and so on, the telescope can be restricted from aiming any closer than a given number of degrees (90°) from the orbital velocity vector. Additionally, the telescope is constrained from looking too close to either the sun (30°), moon (10°), or the limb of the Earth (30°). The limb of the Earth is taken as 12 km from the surface.

Star tracking is halted during periods of "down time" which may be due to the vibration caused by the Space Shuttle docking and off/on loading of payload. Also, an allowance has been made for the disturbance caused by the reboost of the SS from its degraded orbit back to its nominal altitude. This down time consists of the thruster boost phase and a sufficient time to allow for dissipation of the exhaust product contamination.

MISSION ANALYSIS
POINTING CONSTRAINTS

- MINIMUM AVOIDANCE ANGLES (DURING VIEWING AND SLEWING):

  SUN = 30°

  EARTH = 30°

  MOON = 10°

  VELOCITY = 90°

- EARTH LIMB = 12 km

  ORBITAL ALTITUDE = 470 km

- DOWN TIMES DUE TO:

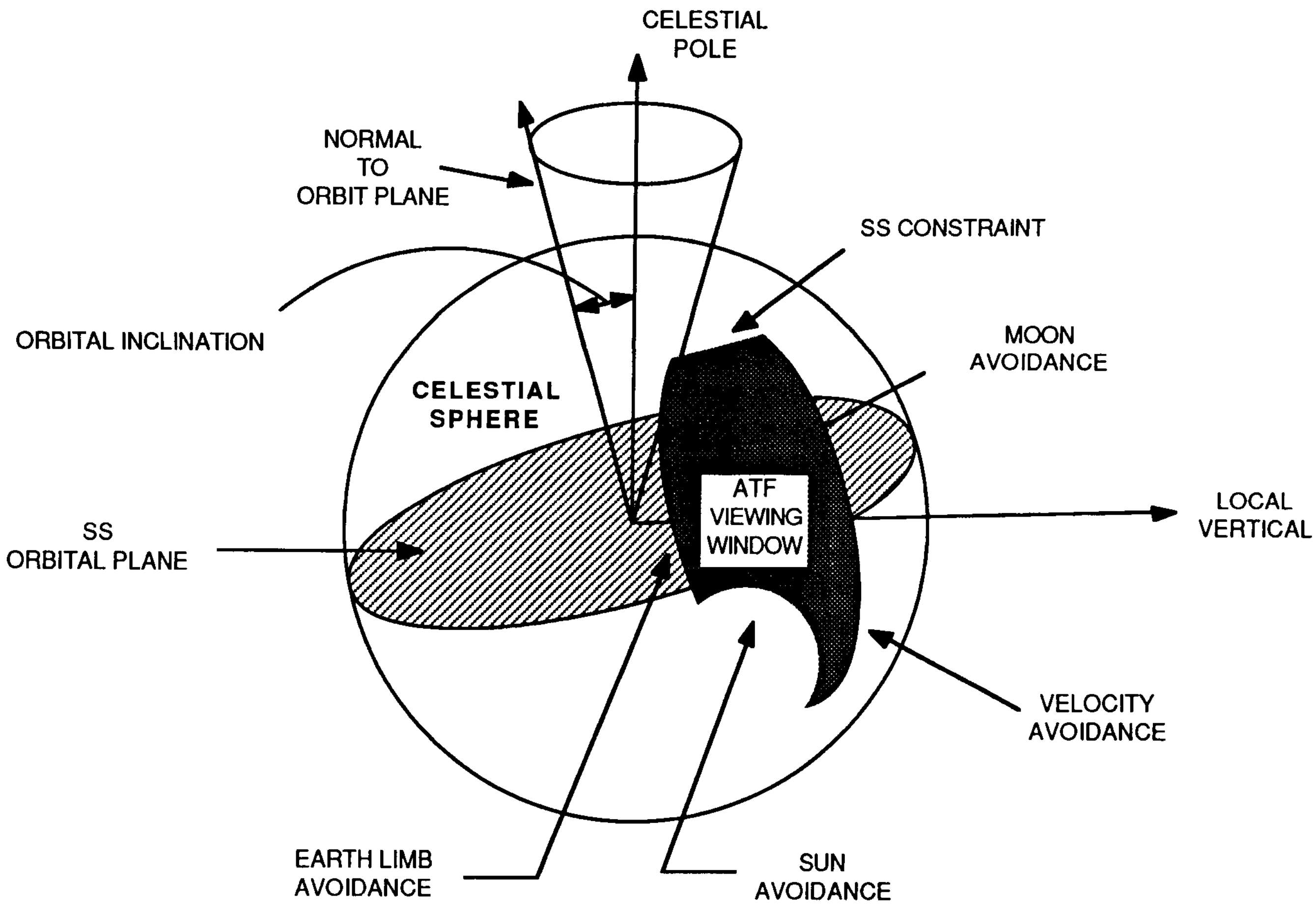
  - SPACE SHUTTLE DOCKING EVERY 90 DAYS WITH DURATION OF SPACE SHUTTLE OFF/ON LOADING = 12 HR

  - SPACE STATION REBOOST AND THRUST CONTAMINATION SETTLING TIME OF 36 HR EVERY 45 DAYS

  - OTHER INTERRUPTIONS TBD

8.2.5 ATF Viewing Window. - Shown here is the SS orbital plane inclined to the celestial pole and the ATF viewing window which has been subjected to various constraints. Stars within this window on the celestial sphere would be available for viewing. This window moves with the SS and offers a different view as the orbit precesses in time.

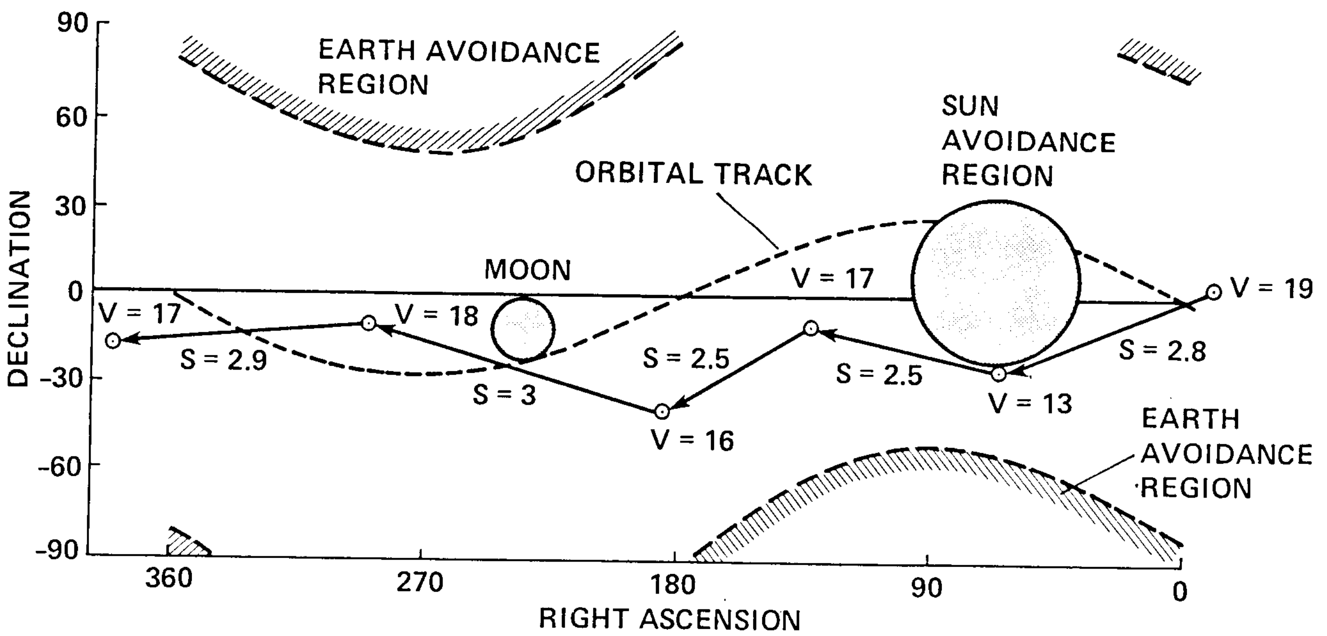
MISSION ANALYSIS
ATF VIEWING WINDOW



8.2.6 Typical Telescope Tracking. - The orbital track of the SS is shown in the dotted line as it traverses over one revolution. The Earth avoidance regions are shown in the cross-hatch area and the sun and moon avoidance are shown by the shaded circles. The selection of stars are shown by the small circles and the viewing time and the slew time are shown along the path.

MISSION ANALYSIS
TYPICAL TELESCOPE TRACKING

S = SLEW TIME, min
V = VIEW TIME, min



8.2.7-1 Results of 1 YR of Operation. - The computer simulation of the star observing strategy was run for one year of ATF operation. The constraints imposed on the ATF are listed on the chart. The ATF was free to view all stars south of the orbital plane (southward = 0°) and to view all stars in the anti-RAM direction (rearward = 0°) subject to the constraints of sun, Earth and Moon avoidance. During 1 yr, the ATF was capable of viewing stars 80.9% of the time. All 127 stars were viewed approximately uniformly during the year for an average total of 56 hr each.

MISSION ANALYSIS
RESULTS OF 1 YR OF OPERATION *

NUMBER OF DIFFERENT STARS	127
TOTAL VIEWING TIME	6978 HR (79.7%)
TOTAL SLEWING TIME	1492 HR
TOTAL DOWN TIME	290 HR
NUMBER OF SIGHTINGS	33,445 (92/DAY)
AVERAGE EQUATORIAL NORMALIZED VIEW TIME PER STAR	24 HR
AVERAGE VIEW TIME PER SIGHTING	12.5 MIN
AVERAGE SIGHTINGS PER STAR	263
AVERAGE SLEW ANGLE	61°
AVERAGE TIME OF A SLEW	2.8 MIN

* ATF MOMENT OF INERTIA = 160,000 $Kg \cdot m^2$; TORQUE FORCE = 30 Nm; MINIMUM VIEWTIME = 7 MIN; AVOIDANCE ANGLES: SUN = 30°, EARTH = 30°, MOON = 10°, VELOCITY = 90°, SOUTHWARD = 0°, REARWARD = 0°

8.2.7-2 Results of 1 YR of Operation (Contd). - A characterization of the average ATF efficiency over a group of stars may be determined by the following equation:

$$\text{AVERAGE EQUATORIAL NORMALIZED VIEW-TIME} = \sum_{i=1}^{N} (T_i / I_i) \Big/ N$$

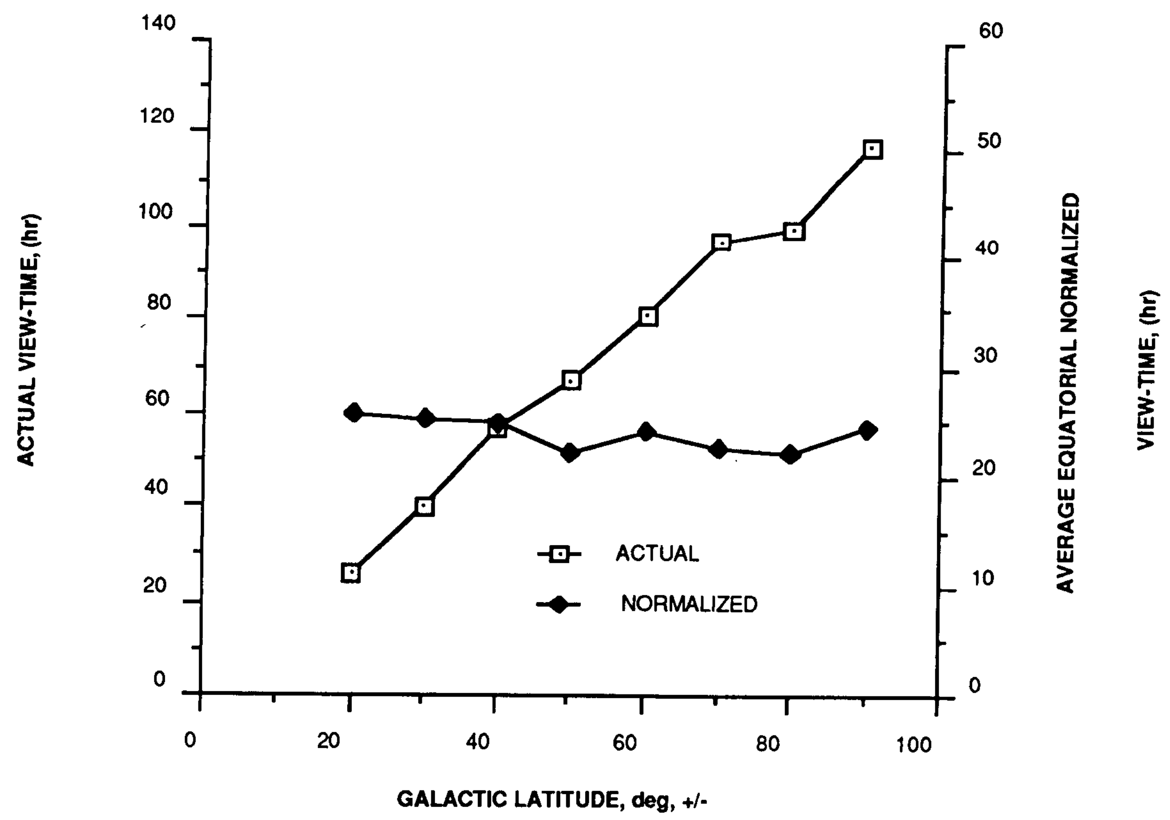
where:

- N = Number of stars being averaged
- T_i = Actual time spent viewing star i
- I_i = Galactic photon rate index for star i

The adjacent chart shows the average equatorial normalized view-time of the complete star-field as well as the average per latitude band. The dotted line shows the actual (unnormalized) view-times averaged over each latitude band.

MISSION ANALYSIS
RESULTS OF 1 YR OF OPERATION

127 STARS



<u>8.2.8 Telescope Aiming Schedule</u>. - A printout is provided of a typical ATF aiming schedule for June 9, 1994. For each time step the schedule shows the proper right ascension and declination to aim the ATF to view the star whose catalog number is given (from 1 to 127). The total view-time accumulated to date is given as well as the expected view-time at this particular sighting. The instantaneous position of the SS is provided and the time and angle needed to slew to the next star is shown.

MISSION ANALYSIS
TELESCOPE AIMING SCHEDULE

TODAYS DATE: JUN. 9, 1994

TIME H/M/S	FOCUS RA	FOCUS DEC	CATALOG NUMBER	VIEWTIME NOW	VIEWTIME* TOTAL	# OF VIEWS	ATF POSITION RA	ATF POSITION DEC	SLEW TIME*	SLEW ANGLE	ORBIT ANGLE
0/ 2/20	0.6	-37.6	1	9.65	136.1	15	29.0	22.4	3.86	117.2	127.1
0/15/50	38.4	6.6	15	8.33	93.4	6	76.8	0.8	2.76	56.5	178.4
0/26/56	17.1	-67.7	7	7.20	76.3	9	115.1	-18.1	3.15	75.9	220.6
0/37/16	124.0	-12.5	44	8.85	130.0	11	156.7	-28.0	3.32	84.7	259.9
0/49/27	219.0	-60.6	78	15.06	125.3	12	207.8	-22.7	3.26	81.6	306.1
1/ 7/46	258.3	-26.5	90	10.67	129.6	11	271.9	7.5	2.44	43.2	15.8
1/20/52	310.8	-25.5	111	9.95	130.3	10	320.6	25.8	2.53	46.9	65.6
1/33/22	331.2	25.1	118	8.21	135.1	12	13.7	26.0	2.71	54.3	113.1
1/44/16	46.4	49.4	18	11.19	93.9	8	55.1	11.8	2.87	61.8	154.5
1/58/20	102.5	-5.1	38	16.86	158.7	10	102.8	-12.9	3.10	72.9	208.0
2/18/18	143.4	-21.4	53	8.93	132.7	13	183.3	-27.6	2.43	42.9	283.9
2/29/40	197.4	28.1	71	12.87	124.1	14	227.9	-15.0	3.08	71.9	327.1
2/45/37	252.6	0.1	89	9.71	130.5	10	282.3	12.8	2.83	59.8	27.7
2/58/ 9	289.5	-7.8	104	5.28	131.2	11	330.9	27.5	2.29	37.6	75.3
3/ 5/43	316.2	38.5	112	8.01	136.3	15	3.4	27.6	2.67	52.5	104.1
3/16/24	38.3	6.7	14	16.93	101.2	7	45.5	16.0	3.23	79.7	144.7
3/36/33	17.1	-67.7	7	7.31	83.5	10	115.0	-18.4	3.15	75.9	221.3
3/47/ 2	5.8	-77.5	5	11.23	130.3	16	157.1	-28.1	1.32	10.3	261.1
3/59/35	219.0	-60.6	77	15.37	125.8	10	209.6	-21.8	2.37	40.3	308.8
4/17/19	281.7	-23.9	98	15.96	130.9	11	271.4	7.7	2.75	56.0	16.2
4/36/ 1	280.6	59.6	99	7.38	134.1	15	344.0	28.5	3.30	83.5	87.3
4/46/42	342.6	-14.5	121	5.07	137.3	14	28.5	22.1	3.40	89.2	127.9
4/55/10	38.4	6.6	15	13.43	101.7	7	59.3	9.4	2.81	59.2	160.1
5/11/24	17.1	-67.7	7	7.34	90.8	11	115.0	-18.5	3.15	75.9	221.8

* MINUTES

8.2.9 Parametric Studies.

8.2.9.1 ATF Slew Rate: The algorithm shown is representative of a time optimal system of slewing the telescope. The settling time represents the time necessary for the ATF to acquire the star and to attenuate any residual jitter.

MISSION ANALYSIS
ATF SLEW RATE

TIME OF SLEW $= 2 * \sqrt{J * \theta / \tau} + K$

WHERE:

K = 15 SEC SETTLING TIME

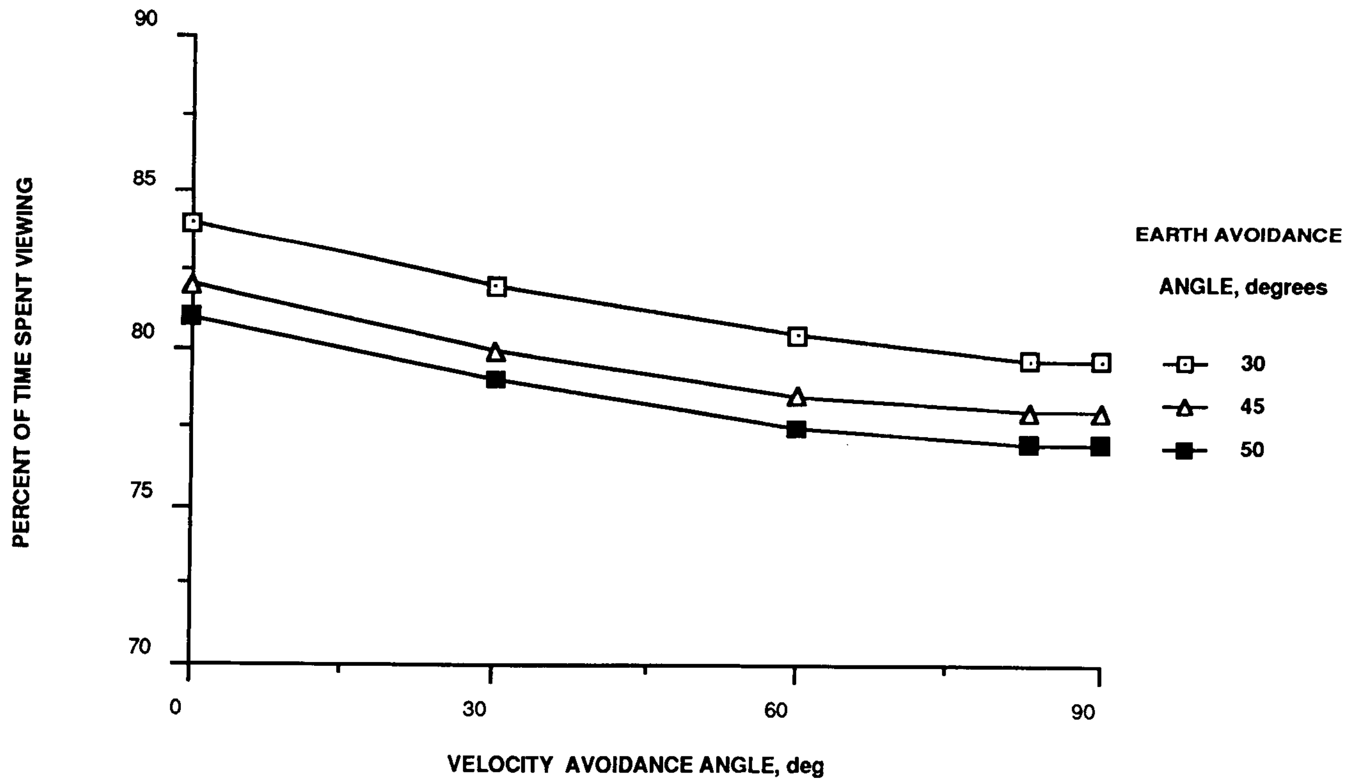
J = 160,000 $Kg \cdot m^2$ MASS MOMENT OF INERTIA

θ = ANGLE OF SLEW FROM ONE STAR TO THE NEXT

τ = 30 Nm TORQUE CONSTANT (COARSE POINTING MOUNT CAPABILITY)

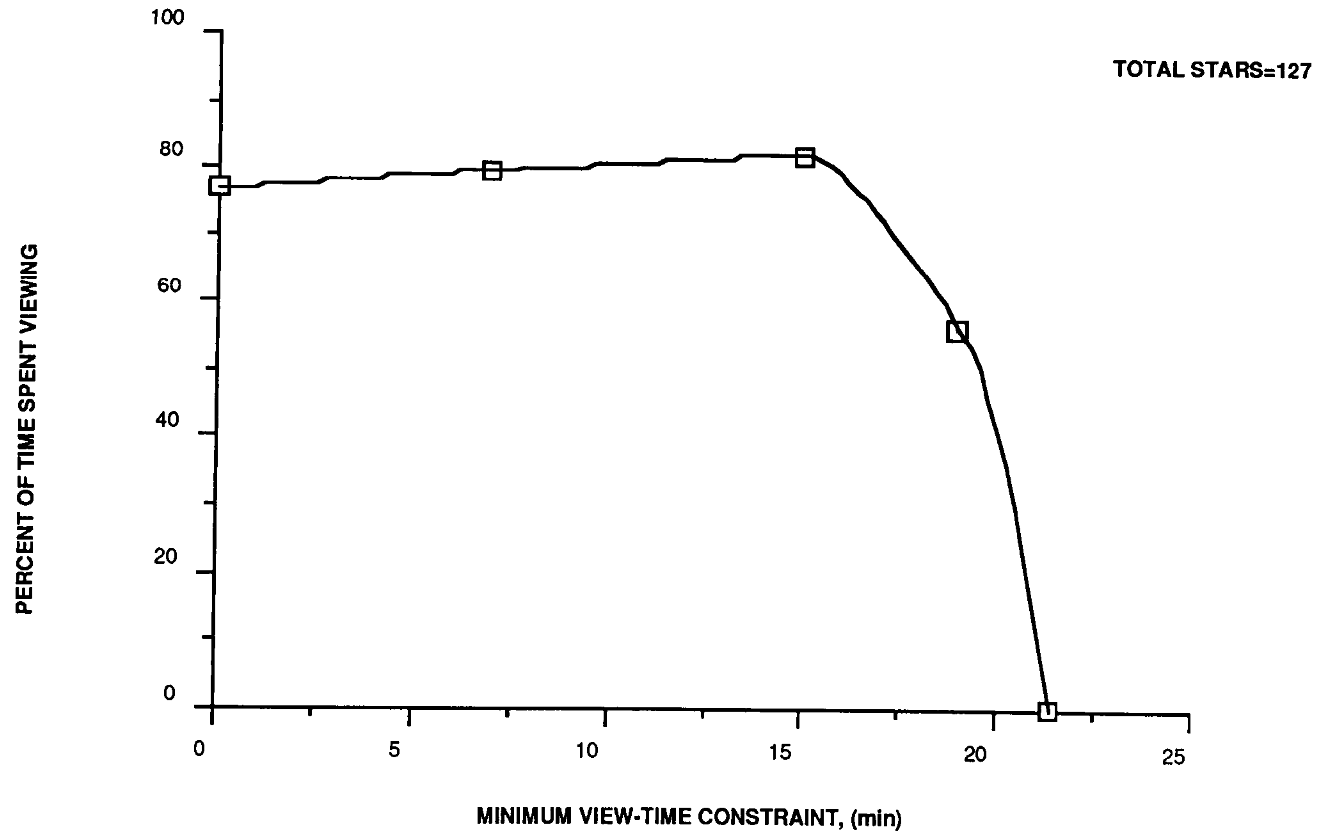
8.2.9.2 Effect of Velocity and Earth Avoidance: The percent of the time spent viewing is shown as a function of the velocity avoidance angle for a range of Earth avoidance angles. Constraining the view from 0 to 90° to the direction of the velocity vector reduced the viewing time by only about 5%.

MISSION ANALYSIS
EFFECT OF VELOCITY AND EARTH AVOIDANCE



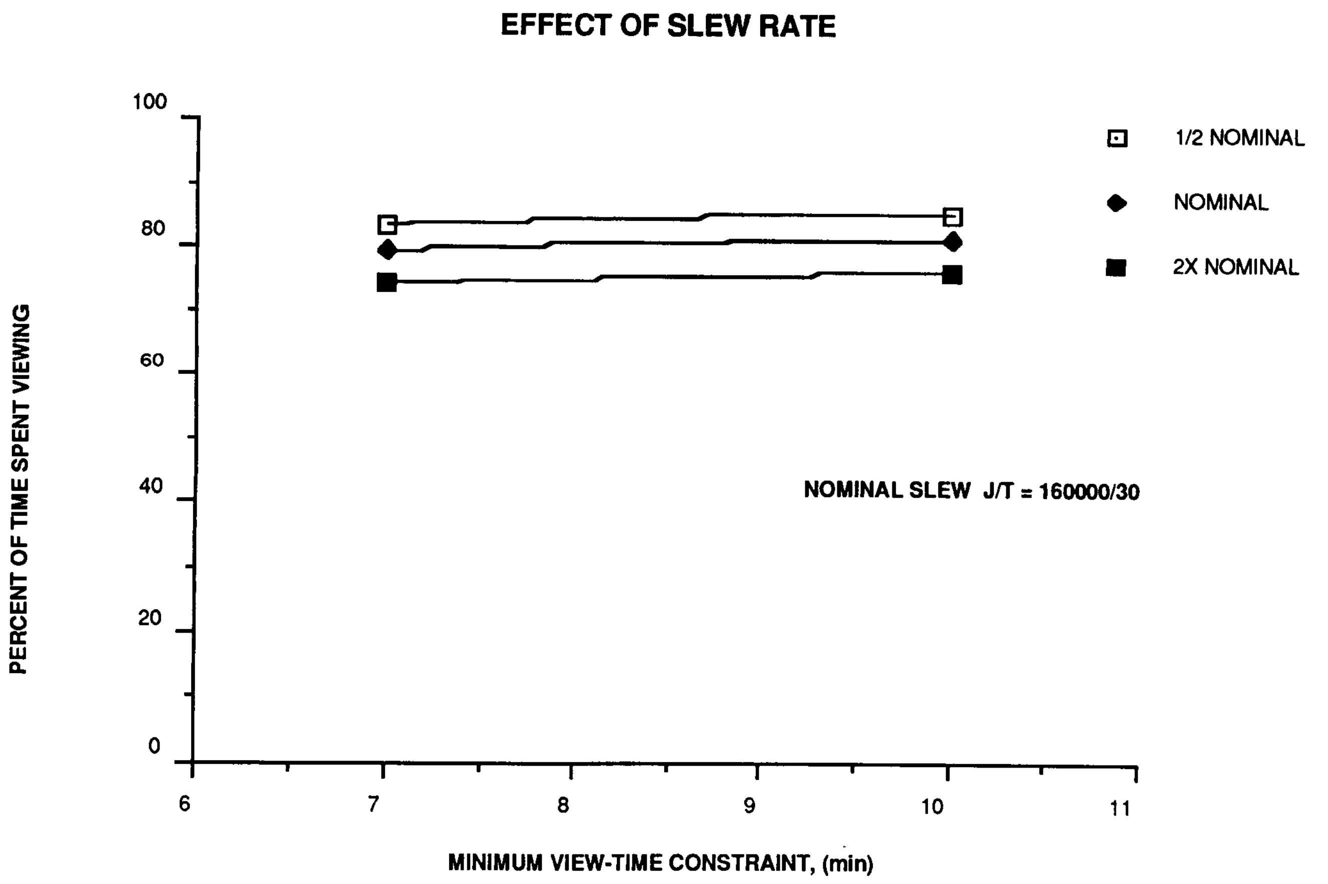
8.2.9.3 Percent Viewing versus View-time Constraint: The effect of constraining the ATF to minimum view-times up to 15 min has a minimal effect on the percentage of time spent viewing over the years. This constraint simply forces the ATF to slew greater angles to view stars which will permit longer view-times. The slight rise in the curve from 0 to 15 min is due to the non-linear nature of the slew time for a given angle. Constraining the view-time to longer views forces larger angles which take a proportionately less percentage of the total time available. The percentage of view-time decreases markedly as the constraint is increased beyond 15 min because the ATF now has to spend time waiting for a target to enter its viewing window, since only a newly entered target will be in sight long enough to meet the view-time constraint.

MISSION ANALYSIS
VIEWING EFFICIENCY VERSUS VIEWTIME CONSTRAINT



8.2.9.4 Viewing Efficiency versus Slew Rates: Shown in this chart is the effect on viewing time of different slew rates which may be representative of telescopes with different moments of inertia and/or torque constraints. The center curve is for the nominal J/T used in this analysis (160000/30) whereas the 2X nominal is for a telescope which has a J/T of twice the nominal.

MISSION ANALYSIS
VIEWING EFFICIENCY VERSUS SLEW RATES

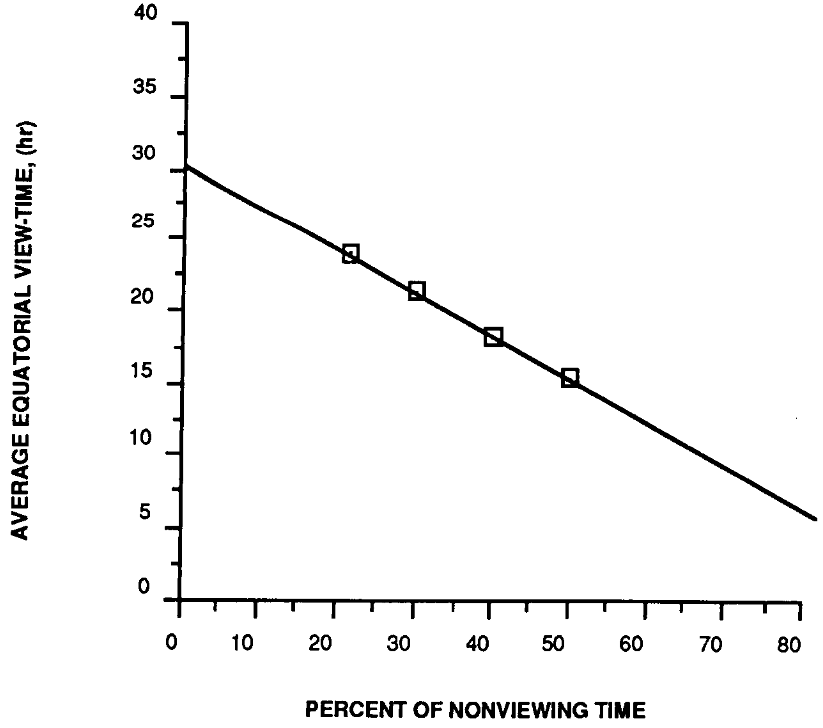


8.2.9.5 Effect of Nonoperating Periods: To determine the effect of down time on the efficiency of the ATF, the star observation strategy was simulated on the full 127-star field for 1 yr of operation under various percentages of nonviewing time. Nonviewing time includes all those times when the ATF is not viewing such as might be caused by slewing, scheduled maintenance, unexpected down times, Space Shuttle docking, off/on loading, SS reboosting because of atmospheric drag, etc. As the chart shows, even a 50% nonviewing time (as assumed in section 3.5) still allows each star to receive an average equatorial normalized view-time of about 22 hr/yr.

MISSION ANALYSIS
EFFECT OF NONOPERATING PERIODS

AVERAGE EQUATORIAL NORMALIZED VIEW-TIME

TOTAL STARS = 127



NONVIEWING TIME INCLUDES:

SLEWING, MAINTENANCE,

DOWN TIME, SPACE SHUTTLE

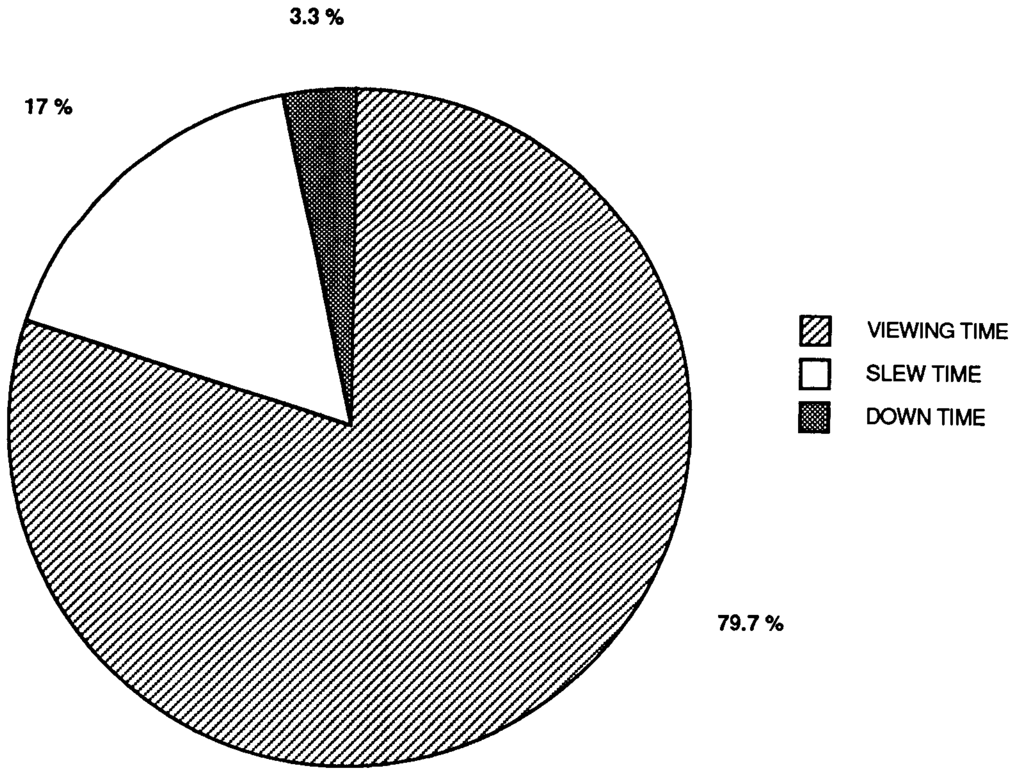
DOCKING, AND SS REBOOSTING

8.2.10 Proportion of Operation Time. - This chart gives a perspective of the proportion of the ATF total operations time spent either viewing, slewing, down time, or those times when no star is available for viewing from the star-field chosen.

ATF SYSTEMS STUDY

MISSION ANALYSIS
PROPORTION OF OPERATION TIME

127 STARS



8.3 Mission Analysis: Modified Star-field

8.3.1 Description of Modified Star-field. - From the original strawman star-field of 127 stars, a set of 100 targets were selected which represented those stars closest to the galactic equator.

This modified star-field still meets the planetary detection requirement for $\approx$ 100 targets, but may not represent an acceptable alternative target list as the only criteria for eliminating stars was their galactic latitudes, and no attempt was made to maintain a mixture of star types.

The only purpose of the modified star-field analysis is to illustrate the effect of the galactic photon rate index described in section 8.2.2 when the stars at the highest latitudes are eliminated. This shows the weighted effect that the highest latitude stars have on viewing efficiency.

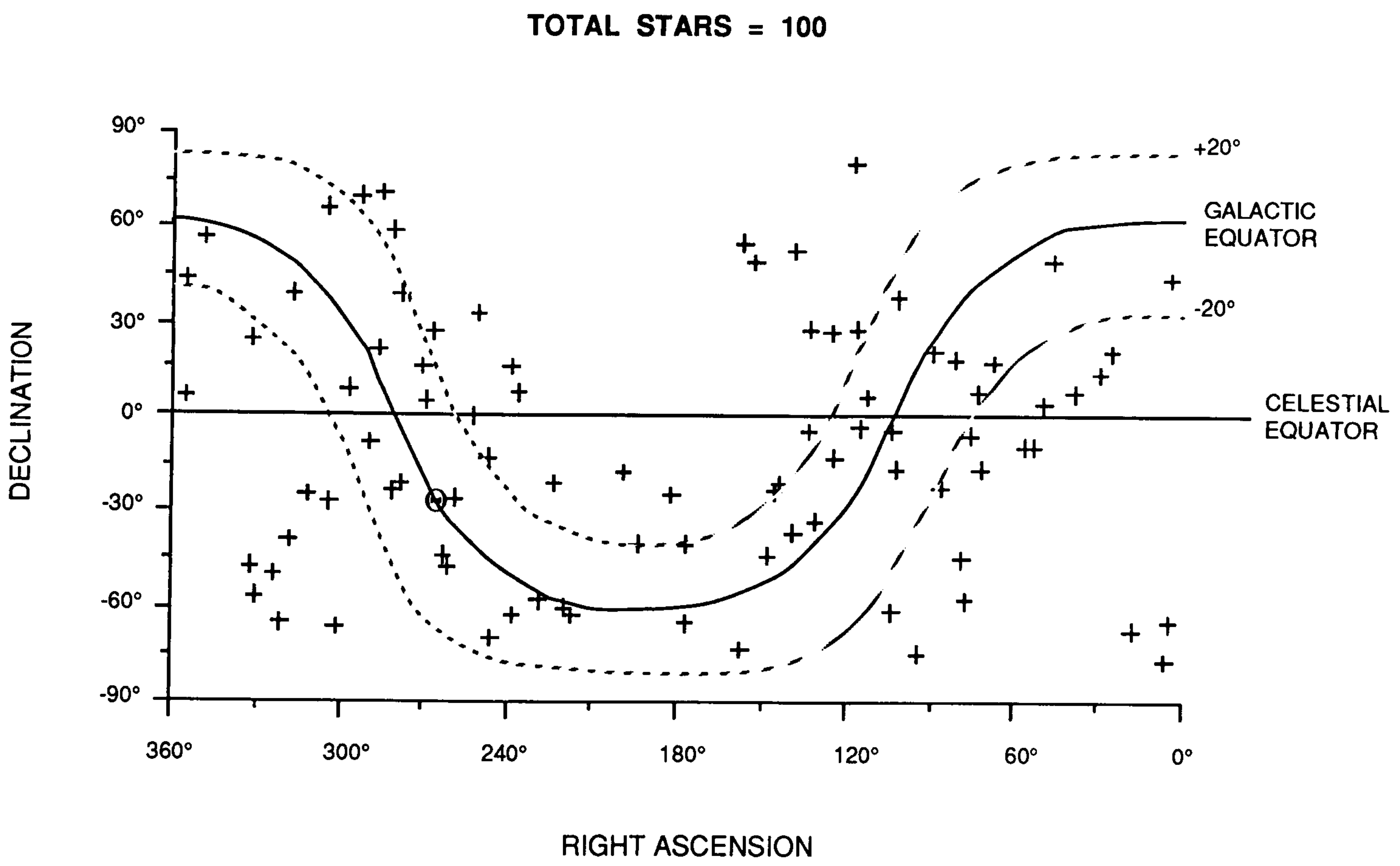
MISSION ANALYSIS
DESCRIPTION OF GALACTIC STAR-FIELD

- TOTAL NUMBER OF STARS: 100

- STARS LIE IN A REGION APPROXIMATELY ± 60° FROM THE GALACTIC EQUATOR

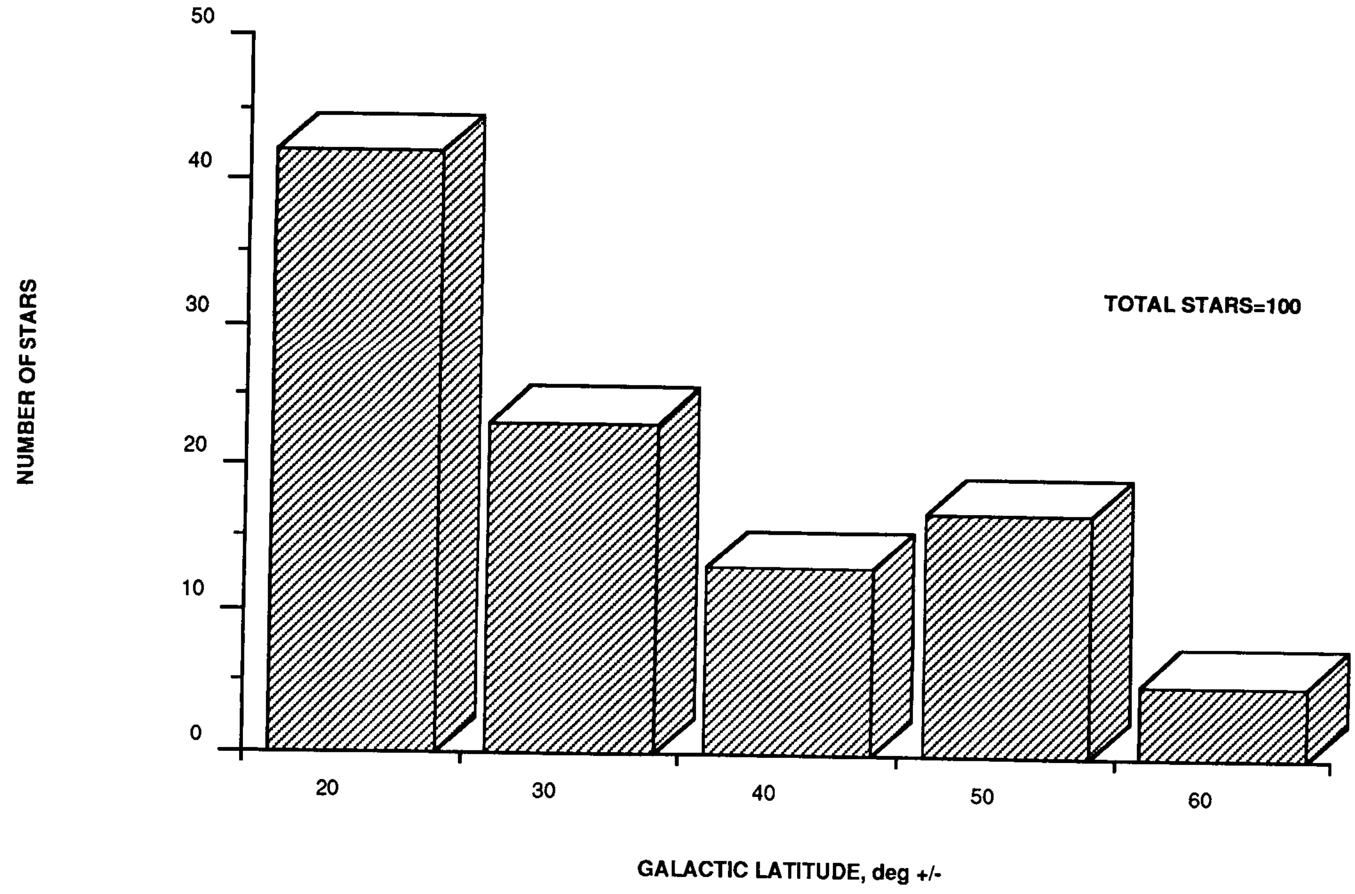
8.3.2 Location of Stars. - Shown on the adjacent chart is the location of each of the 100 stars that were selected from the original star-field. The galactic equator is shown as a dashed line.

MISSION ANALYSIS
LOCATION OF 100-STAR FIELD



8.3.2.1 Number of Stars in Each Latitude Band: The galactic latitude was divided into bands of 10° each for the purpose of assigning an index which would increase the view-time for stars within bands at higher latitudes. Stars within the bands of 0 to 20° were considered in the same band and were assigned the same index.

MISSION ANALYSIS
NUMBER OF STARS IN EACH LATITUDE BAND



8.3.3-1 Results of 1 YR of Operation. - The computer simulation of the star observation strategy was run for one year of ATF operation using the 100-star field. The constraints imposed on the ATF were the same as those used in the previous analysis with the results shown here.

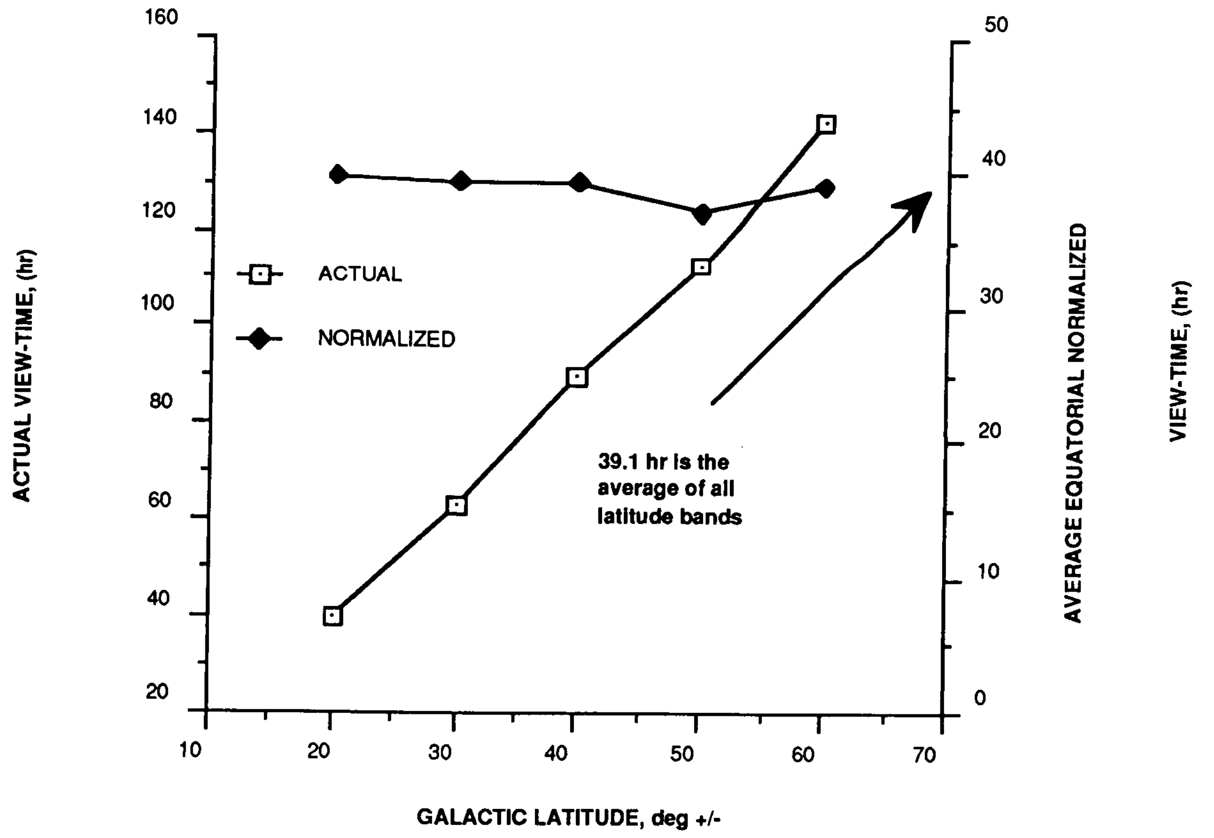
MISSION ANALYSIS
RESULTS OF 1 YR OF OPERATION *

NUMBER OF DIFFERENT STARS	100
TOTAL VIEWING TIME	6912 HR (78.9%)
TOTAL SLEWING TIME	1564 HR
TOTAL DOWN TIME	284 HR
NUMBER OF SIGHTINGS	34,519 (94/DAY)
AVERAGE EQUATORIAL NORMALIZED VIEW TIME PER STAR	39 HR (DEFINED IN SECTION 8.2.7-2)
AVERAGE VIEW TIME PER SIGHTING	12 MIN
AVERAGE SIGHTINGS PER STAR	345
AVERAGE SLEW ANGLE	63°
AVERAGE TIME OF A SLEW	2.8 MIN

* REQUIRED VIEW-TIME INCREASES WITH INCREASING GALACTIC LATITUDE

8.3.3-2 Results of 1 YR of Operation (Contd). - The adjacent chart summarizes the actual and normalized view-times for the modified star-field.

MISSION ANALYSIS
RESULTS OF 1 YR OF OPERATION (100 STARS)

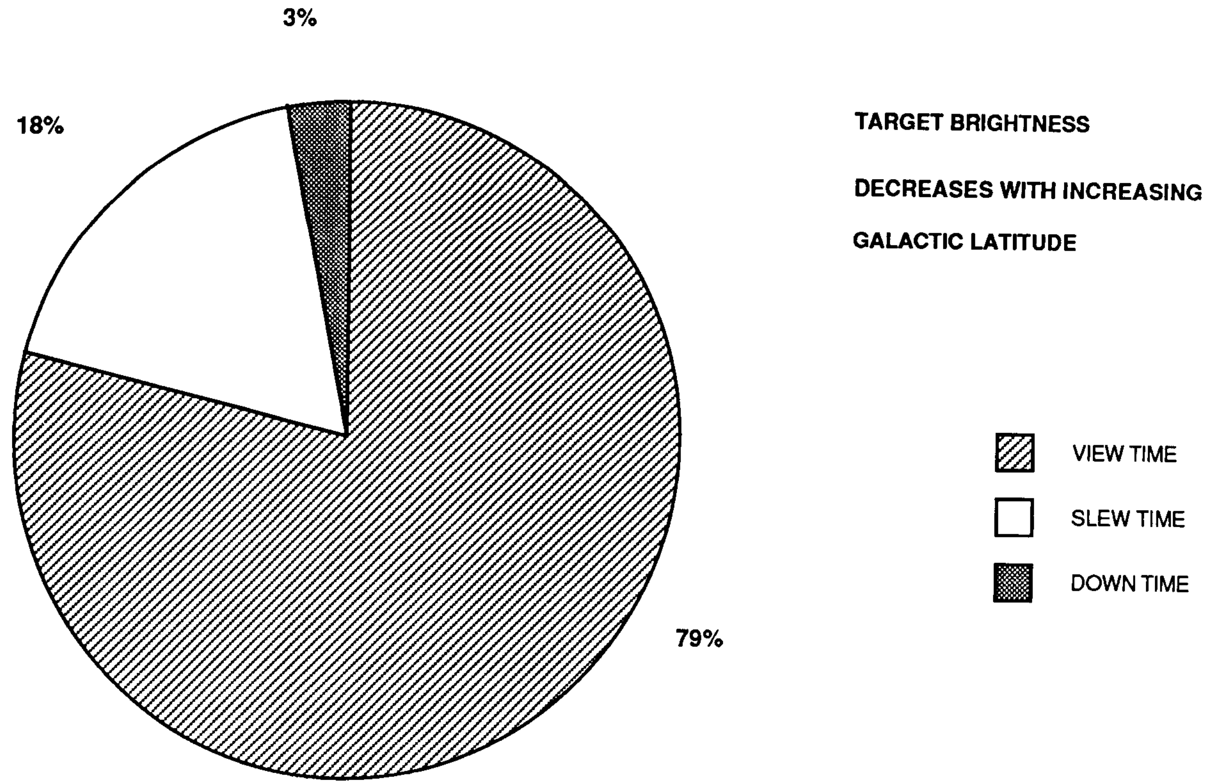


8.3.4 Proportion of Operation time. - This chart gives a perspective of the proportion of the ATF total operations time spent either viewing, slewing, down time, or those times when no star is available for viewing from the 100-star field. At no time was the ATF unable to view a star.

ATF SYSTEMS STUDY

MISSION ANALYSIS
PROPORTION OF OPERATION TIME

100 STARS



TARGET BRIGHTNESS

DECREASES WITH INCREASING

GALACTIC LATITUDE

8.4 Summary

Under the baseline constraints, the ATF should be able to view all sky regions approximately equally over its lifetime, spending about 79 to 81% of its time viewing stars.

The performance of the ATF is only slightly decreased with the imposition of more severe pointing constraints.

Based on a galactic latitude photon rate index which accounts for the lower brightness of stars at higher galactic latitudes, the ATF should be able to provide each star with an average equatorial normalized view-time of about 24 hr/yr.

Although this analysis is based on selected stars for Planetary Detection purposes, the results would be similar for stars chosen for astrophysical opportunities. Since the efficiency of the ATF is high, there should be time available for other than planetary detection purposes.

MISSION ANALYSIS SUMMARY

- ATF VIEWING EFFICIENCIES OF ≈80% APPEAR ACHIEVABLE
- THE ATF IS RELATIVELY INSENSITIVE TO POINTING CONSTRAINTS
- THE ATF IS EXPECTED TO BE ABLE TO PROVIDE AT LEAST 1 OBSERVATION/YR FOR EACH TARGET (≈24 HR/YR OF EQUATORIAL NORMALIZED VIEWTIME)

9.0 MISSION OPERATIONS

9.1 Requirements

The ATF mission operations will begin when the Facility is delivered to the SS and will include the activities needed to assemble the Facility and prepare for science observations. Mission operations will also include all the activities needed to collect useful science data and prepare the data for subsequent scientific analysis.

MISSION OPERATIONS REQUIREMENTS

- PLAN AND IMPLEMENT ON ORBIT ASSEMBLY, CHECKOUT, AND INITIAL OPERATIONS
- PLAN AND IMPLEMENT OBSERVATION SCHEDULES FOR PLANETARY DETECTION TARGETS TO SATISFY SCIENCE REQUIREMENTS
- PERFORM SECONDARY OBSERVATIONS FOR GUEST INVESTIGATORS
- ADJUST PLANS TO COMPENSATE FOR INTERRUPTIONS CAUSED BY THE SS OR OTHER SOURCES
- ARCHIVE RAW AND PROCESSED OBSERVATION DATA

9.2 Assumptions

The ATF operations will be influenced by the activities of other payloads as well as by those of the SS and the STS. However, details of the station operational environment are not known at this time. To develop a strawman ATF Operations Concept, assumptions have been made about interactions with SS and other payloads.

MISSION OPERATIONS ASSUMPTIONS

- THE ATF WILL RECEIVE HIGH PRIORITY FOR USE OF SS RESOURCES DURING ASSEMBLY AND CHECKOUT
- DURING NORMAL OPERATIONS, ATF WILL NEED A MINIMUM OF PLANNING COORDINATION WITH THE SS AND WITH OTHER PAYLOADS
- ATF OPERATION INTERRUPTIONS DUE TO SPACE STATION AND OTHER SOURCES WILL BE INFREQUENT OR SHORT
- SPACE STATION WILL PROVIDE WARNING AND ALL-CLEAR SIGNALS FOR DISTURBANCE EVENTS

9.3 ATF Operation Functions

The functions which will be performed to collect and process scientific data are shown on the opposite page.

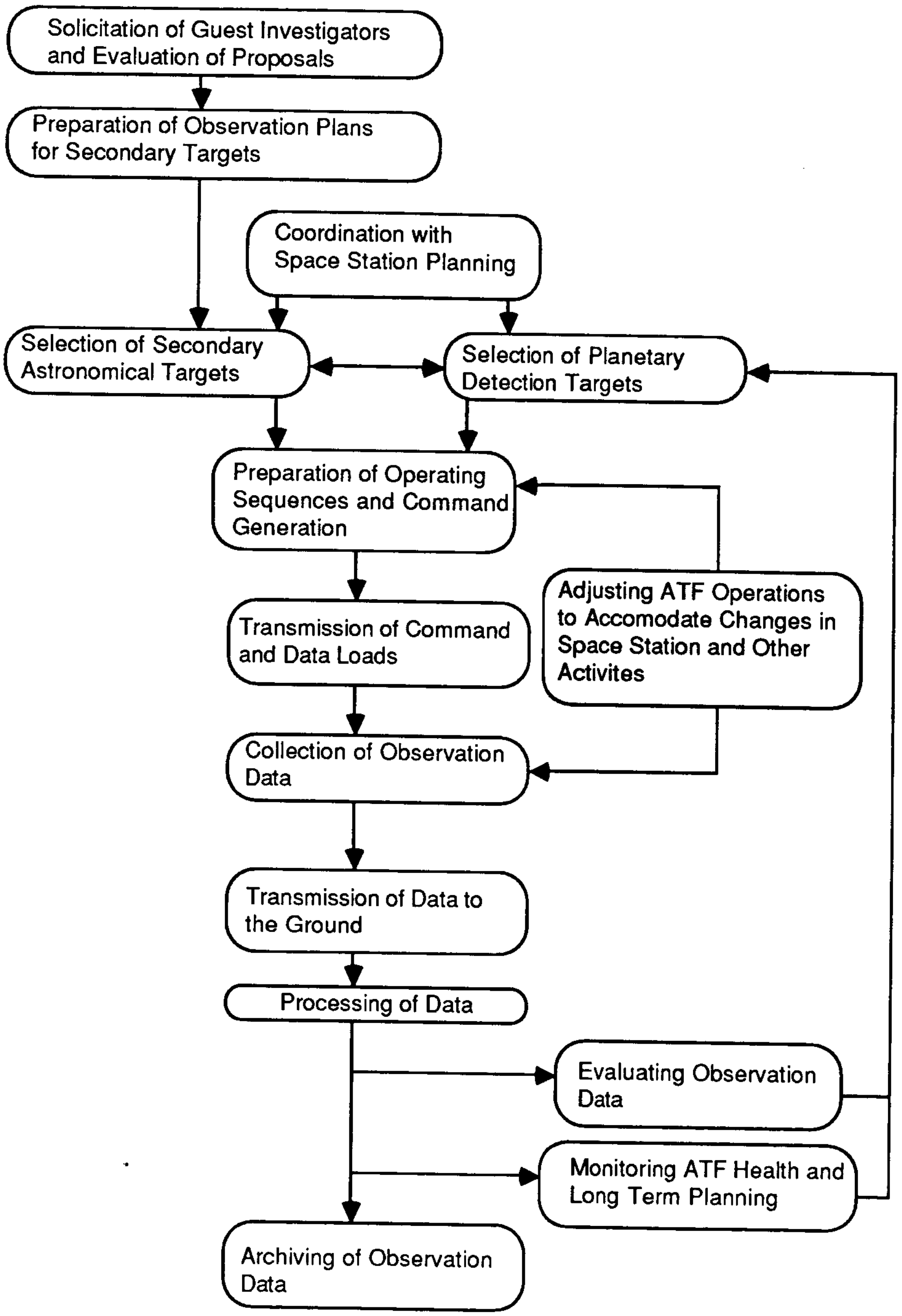
Selection of the Guest Investigators will be performed by NASA Headquarters, with assistance from the ATF operations staff. After the guest investigators have been selected, the ATF staff and the guest investigators will prepare specific lists of targets and their associated reference stars. These targets will be combined with the Planetary Detection targets to prepare observation timelines. The timelines will incorporate known SS activities which would interfere with ATF data collection.

The observation timelines will be used to prepare detailed ATF command sequences which will control the telescope pointing and scientific data collection.

The data will be transmitted to the Ground Operations Center and examined to verify the quality of the observation and ATF health.

Both unprocessed and processed data will be archived for subsequent scientific analysis.

MISSION OPERATIONS
ATF OPERATIONS FUNCTIONS



9.4 Operations Plans

9.4.1 Assembly, On-Orbit Checkout, and Initial Operation Tasks. - After the ATF is delivered to the SS, the ATF will be assembled, checked out, and calibrated. A nominal sequence of tasks is listed on the opposite page.

MISSION OPERATIONS
ASSEMBLY, ON-ORBIT CHECKOUT, & INITIAL OPERATION TASKS

- ASSEMBLY
  - ASSEMBLE TELESCOPE
  - ASSEMBLE TELESCOPE ON POINTING MOUNT
  - VERIFY INTERFACES TO SS
- CHECKOUT
  - CHECKOUT TELESCOPE SUBSYSTEMS AND VERIFY SS ENVIRONMENT
  - CHECKOUT FPI
  - OPEN APERTURE COVER
  - ADJUST AND FOCUS OPTICS
- INITIAL OPERATION
  - RUN TEST OBSERVATION SEQUENCE (7 DAYS)

9.4.2 Baseline Observation Concept — Normal Operation. - The Baseline Observation Concept for normal operation is described on the opposite page.

The minimum turnaround period for ATF planning and control ($\approx$ 4 days) is constrained by the required ground-operations activities. The maximum turnaround period is constrained by the need to periodically update the observation schedule to reschedule missed observations or add guest investigator targets.

A 7-day planning cycle has been selected for telescope control operations. This period was selected for the convenience of ground operations personnel and appears well matched to the SS planning cycles.

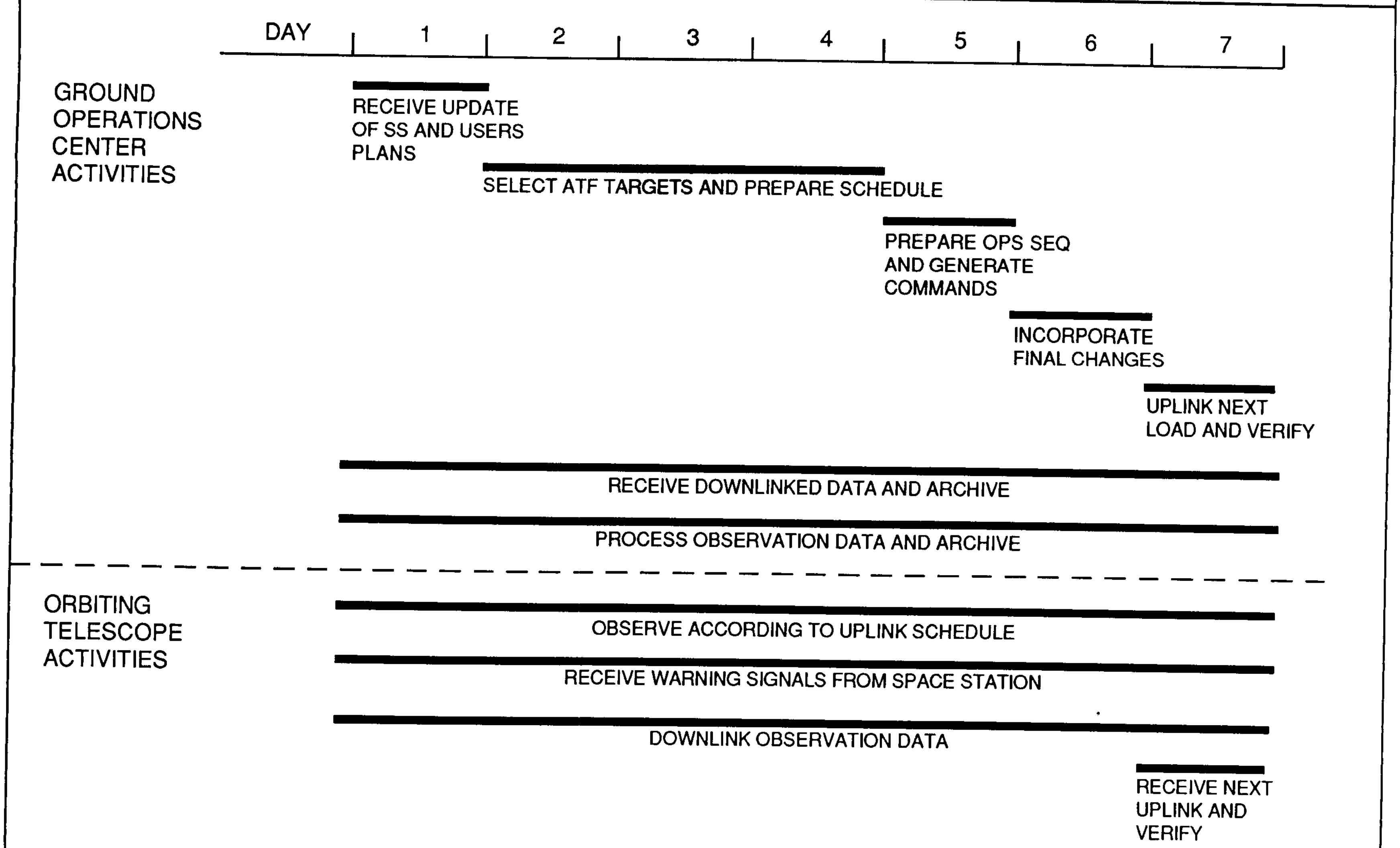
MISSION OPERATIONS
BASELINE OBSERVATION CONCEPT (NORMAL OPERATIONS)

- NORMAL OPERATIONS
  - ALL PLANNING, COMMAND GENERATION, MONITORING, AND DATA PROCESSING WILL BE PERFORMED AT THE GROUND OPERATIONS CENTER
  - TELESCOPE WILL FOLLOW UPLINKED TIMELINE UNLESS INTERRUPTED BY UNSCHEDULED SS EVENT
  - EACH OBSERVATION WILL BE PERFORMED BY STANDARD ACTIONS AND WILL BE INDEPENDENT OF PRECEDING AND FOLLOWING OBSERVATIONS
  - NORMAL TIME PERIOD FOR TELESCOPE CONTROL — 7 DAYS
  - OBSERVATION DATA WILL BE IMMEDIATELY DOWNLINKED TO THE GROUND WITH 24 HR DELIVERY TO THE GROUND OPERATIONS CENTER
  - ALL RAW AND PROCESSED DATA WILL BE ARCHIVED

9.4.3 Normal Timeline. - The weekly timeline for normal operations is shown on the opposite page.

ATF SYSTEMS STUDY

MISSION OPERATIONS NORMAL TIMELINE



9.4.4 Baseline Observation Concept — Anomaly Responses. - The Baseline Observation Concept incorporates simple preprogrammed responses to anomalies or unscheduled interruptions of the planned observing timeline. The science requirements allow long windows for scheduling observations, so that missed observations do not need to be rescheduled for a few weeks.

Unscheduled events that might cause permanent damage to the telescope, such as contamination deposits from venting, or a loss of SS services that might result in a pointing error, will be responded to by closing the aperture cover and suspending observations. After the event is over, ATF will resume the original timeline and missed observations will be rescheduled by the Ground Operations Center.

Unscheduled SS events that might affect data collection, but not damage ATF, such as obstruction of the field-of-view, severe vibrations, or down-link interruptions, will be recorded by the ATF operations personnel, but data collection will continue. The questionable data will be analyzed at the Ground Operations Center and the observations rescheduled if necessary.

Anomalies in an ATF subsystem will cause the ATF to switch to a safe-hold mode until analysis can be performed at the Ground Operations Center. When the anomaly is diagnosed, corrective commands will be transmitted to reconfigure the ATF and resume observing. Observations that were missed will be rescheduled.

MISSION OPERATIONS
BASELINE OBSERVATION CONCEPT (ANOMALY RESPONSES)

ANOMALY	RESPONSE
UNSCHEDULED SS EVENT	TELESCOPE -- CLOSE COVER, SUSPEND OBSERVING, RESUME TIMELINE AFTER ALL-CLEAR IS RECEIVED GROUND OPS CENTER -- RESCHEDULE MISSED OBSERVATIONS
POINTING ERROR, TELESCOPE SYSTEM ANOMALY, POWER ANOMALY	TELESCOPE -- SWITCH TO SAFE-HOLD MODE GROUND OPERATIONS CENTER -- DIAGNOSE ERROR AND UPLINK CORRECTIVE COMMANDS, RESCHEDULE MISSED OBSERVATIONS
DOWNLINK ANOMALY WITH DATA LOSS, POOR DATA, ETC.	TELESCOPE -- CONTINUE OBSERVING AS SCHEDULED GROUND OPS CENTER -- ANALYZE DATA AND RESCHEDULE REPEAT OBSERVATIONS IF NECESSARY

9.5 Open Issues Trade Studies

The strawman ATF operations concept which has been described will satisfy the mission requirements. Several issues have been identified, however, which will need additional study.

The sequence of initial assembly and checkout after the ATF is delivered to the SS will depend on the resources available at the station. For example, if the station service bay includes a Standard Interface Adapter, then the ATF command and data interface can be verified while the ATF is still in the bay. If the bay does not include a Standard Interface Adapter, the ATF interface verification will be performed after the ATF is attached to the CPS.

Several candidate applications of computer-based intelligent systems to mission operations have been identified. For a long-life mission with many repeated observations of the same targets, such as the ATF, there may be cost savings from automating some of the operations tasks.

The requirement to archive all raw and processed data can potentially produce a large volume of storage. Optical disks are candidate storage media although widely used standards have not yet evolved.

MISSION OPERATIONS
OPEN ISSUES AND TRADE STUDIES

- AMOUNT OF CHECKOUT PERFORMED IN SS ASSEMBLY BAY BEFORE TELESCOPE IS ASSEMBLED ONTO POINTING MOUNT
- APPLICATION OF COMPUTER-BASED INTELLIGENT SYSTEMS
  - SCOPE OF TELESCOPE RESPONSE TO SS EVENT WARNING SIGNALS
  - SCOPE OF TELESCOPE RESPONSE TO WARNING SIGNALS FROM SUN, EARTH, AND SS PROXIMITY SENSORS
  - ALLOCATION OF REPLANNING TASKS BETWEEN GROUND OPERATIONS CENTER AND THE ORBITING TELESCOPE
- STORAGE MEDIUM USED FOR ARCHIVED DATA

10.0 TEST

10.1-1 Testing Baseline Concepts

The ATF test program will be designed to provide confidence that the flight articles will operate successfully during flight via a series of functional, environmental, qualification, and protoflight tests. Since ATF will be a H/W-limited program to save costs, protoflight tests will be used to fulfill the functions of both qualification (coupled with test model data) and acceptance tests on the flight article. Acceptance tests will be conducted on flight units to disclose workmanship defects in time to permit correction prior to use in system tests.

The dynamic mechanical environments for protoflight tests are to be 1.25 times the predicted flight amplitudes for launch durations. Performance margins are to be demonstrated on selected parameters such as power supply voltage to verify proper system performance with values both higher and lower than the expected operating ranges.

Functional and environmental tests are to be performed at the unit, assembly/subsystem, and system levels.

Units not previously qualified, to be subjected to qualification testing. Environments imposed will be equivalent to 1.5 times the predicted flight levels.

TEST
TESTING BASELINE CONCEPTS

- SYSTEM LEVEL TESTS
  - TWO CONFIGURATIONS
    - LAUNCH, THREE PIECES
    - ON-ORBIT, 21.5 m LONG
  - PROTOFLIGHT SYSTEMS TESTS
    - ONE SYSTEM, TEST AND FLIGHT
    - VERIFY 1.25 DESIGN MARGIN FOR DYNAMIC LOADS
    - VERIFY PERFORMANCE MARGIN FOR SELECTED PARAMETERS
  - SELF TEST, SYSTEM LEVEL END-TO-END TESTS — TBD
  - SPECIAL SUBSYSTEM OPTICAL TESTS — TBD
- UNIT LEVEL TESTS
  - QUALIFICATION TESTING, ALL UNITS WILL BE TESTED TO VERIFY 1.5 DESIGN MARGIN FOR DYNAMIC LOADS

10.1-2 Testing Baseline Concepts (Contd)

The FPI will be functionally and environmentally tested at the unit and system levels.

Flight, spare, and refurbished units will be tested to acceptance amplitudes for acceptance durations.

The EVA operations for on-orbit assembly of the ATF will be demonstrated in a neutral buoyancy facility.
Protoflight tests have been used for most of the current flight-H/W programs where funding has been constrained.
In addition to the programs shown, HST also has chosen the protoflight test approach.

TEST
TESTING BASELINE CONCEPTS (CONTD)

- FOCAL PLANE INSTRUMENT
  - FUNCTIONALLY AND ENVIRONMENTALLY TESTED AT SUBASSEMBLY AND TELESCOPE LEVELS
- FLIGHT, SPARES, AND REFURBISHED UNITS
  - SCREEN FOR WORKMANSHIP BY FLIGHT LEVEL ENVIRONMENTAL TEST
- ON-ORBIT PROCEDURE VERIFICATION TESTING IN NEUTRAL BUOYANCY FACILITY
- HERITAGE
  - PROTOFLIGHT — PIONEER VENUS, GALILEO, AND IRAS

10.2 Model Candidates

Various test models will be built as development test vehicles during the early phases of the program and as aids in qualification testing later in the program. The major program test models are as follows:

Structural Model. -This model would be constructed using the same design, materials, production techniques and tooling planned for the flight item. The fabrication and assembly would adhere to engineering drawings and procedures with modifications made as required. Because of the fabrication times and expense involved, the telescope structure with mass models mounted to it will be used for some of the early environmental testing. Care will be taken and restrictions imposed on the conduct of these tests to prevent overstress of the flight items.

Thermal Model. -This model could be constructed in the manner described for the structural model. Care will be taken to duplicate the flight-design surface finishes. Some flight items such as the sunshade may be tested separately early in the program.

Electrical Brassboard. -Critical circuits will be brassboarded and tested early in the program and will be used throughout the test program for troubleshooting.

Optical Subsystem Models. -The Optics Subsystem will have development models fabricated and tested.

TEST MODEL CANDIDATES

PHYSICAL MODELS

- STRUCTURAL
- THERMAL
- ELECTRICAL BRASSBOARDS
- OPTICAL

ANALYTICAL MODELS

- STRUCTURAL
- THERMAL
- OPTICAL
- POINTING CONTROL
- CONTAMINATION

10.3 Facilities

A survey was made of facilities that may be available to test a telescope assembly the size of the ATF. Included were facilities necessary to conduct thermal vacuum and acoustic test, and neutral buoyancy facilities for EVA simulations and training.

Acoustic Testing — There is at least one existing facility that appears to meet the MIL-STD requirement of a chamber volume being 10 times greater than the volume of the test item.

Thermal/Vacuum Testing — There are several government and contractor facilities that could be used for system level Thermal/Vacuum testing. Two of the chambers identified were developed for military programs and may pose scheduling problems.

Neutral Buoyancy Activities — Facilities at MSFC are presently being used for large telescope and SS EVA simulation and training. A Space Shuttle model is also available for this use if needed. There is a larger facility in the planning stage that is specifically intended for SS training.

TEST
EXISTING TEST FACILITIES

- LAUNCH VIBRATION ENVIRONMENT
  - CONFIGURATION — TWO PIECES
  - FACILITIES — TBD
- ON-ORBIT ENVIRONMENT
  - CONFIGURATION — 70-FT LONG TELESCOPE
  - THERMAL VACUUM CHAMBERS

SIZE	LOCATION
15.2 m DIAMETER BY 27.4 m HIGH	JSC
12.8 m DIAMETER BY 25 m HIGH	AEDC, TULLAHOMA, TN
7.3 m DIAMETER BY 22.9 m LONG	LMSC, SUNNYVALE, CA

- NEUTRAL BUOYANCY ENVIRONMENT
  - CONFIGURATION — 21.5-m-LONG TELESCOPE
  - TBD

11.0 ATF CONCLUSIONS

C-5

11.1 Science

The motivations behind the search for extrasolar planetary systems are twofold. First, to test the Copernican Principle by supplying the answer to a major missing element: Are planets and planetary systems common? And second, to test our theoretical understanding of the processes by which stars and planetary systems are formed.

To ensure a meaningful result, even in the case that no planets are detected, it is necessary that a statistically significant number of target stars be studied, and that the detection limit of the experiment be sufficiently low to detect "ordinary-sized" planets of 10-20 Earth masses (e.g., Uranus/Neptune).

Various workshops and reviews since 1974 have led to the conclusion that astrometry is the most promising near-term approach to Planetary Detection. This conclusion has been reached in light of the derivable parameters, the accuracy of the measurement, and the current state (and expected improvement) of technology.

CONCLUSIONS

SCIENCE

- A SEARCH FOR PLANETARY SYSTEMS AROUND OTHER STARS IS AN IMPORTANT STEP IN CONFIRMATION OF CURRENT THEORIES ABOUT THE FORMATION OF PLANETS AND STARS.
- TO ENSURE A SIGNIFICANT RESULT (EVEN IN THE EVENT OF NO DETECTIONS), A SUBSTANTIAL NUMBER OF TARGETS MUST BE EXAMINED WITH DETECTION SENSITIVITY DOWN TO AT LEAST 10-20 EARTH MASSES.
- NUMEROUS WORKSHOPS AND REVIEWS HAVE ESTABLISHED THAT ASTROMETRY IS THE MOST PROMISING NEAR-TERM APPROACH.

11.2 Measurement Approach

The selection of measurement approach used in the ATF is crucial to the system's ability to meet the astrometric accuracy and stability requirements. These requirements when applied to conventional direct imaging approaches yield detector requirements of $10^4 \times 10^4$ pixels in a 50-mm square, with a dimensional stability of 1 part in 10^6, and a photometric stability across a pixel of 1 part in 10^4, over a span of some 20 yr. This level of performance is significantly beyond currently available technology.

The astrometric approach used in the ATF strawman conceptual design is to use a moving Ronchi ruling to impose the metric information onto the star signals and a Multichannel Astrometric Photometer to detect these signals. This approach results in a highly differential measurement resistant to systematic errors, and capable of being made within the current state of the art.

CONCLUSIONS

MEASUREMENT APPROACH

- CONVENTIONAL ASTROMETRY THROUGH DIRECT IMAGING ON A SPACIALLY RESOLVING SENSOR REQUIRES DIMENSIONAL STABILITY AND PHOTOMETRIC UNIFORMITY BEYOND THE CURRENT STATE OF THE ART.

- THE ATF APPROACH USES A RONCHI RULING AT THE PRIME FOCUS OF A TELESCOPE TO PROVIDE A HIGHLY DIFFERENTIAL RELATIVE MEASUREMENT OF STAR LOCATIONS.

- THE DIFFERENTIAL MEASUREMENT MAKES THE APPROACH RESISTANT TO SYSTEMATIC ERRORS.

11.3 ATF Strawman Concept

11.3.1 System Requirements/Characteristics. - The primary driver of ATF system requirements is that the system be capable of detecting Uranus/Neptune class planets around a statistically significant number (≈100) of target stars. To achieve the requisite target population, the system must function to distances of about 10 parsecs, at which distance, detection of Uranus/Neptune class planets, requires an astrometric accuracy of approximately 10 μarcsec.

To achieve these requirements within the available viewing time, an ATF strawman design was developed that uses a f/13, single-mirror, reflecting telescope with a 1.25-m aperture. The entire telescope package measures 21.5 m long by 1.85 m diameter, with the Ronchi ruling located on axis at the prime focus, and the Multichannel Astrometric Photometer (MAP) mounted on the side of the telescope tube.

Rather than designing a free-flying spacecraft to carry the telescope, the strawman ATF uses the SS as a stable long-term platform for telescope mounting, and makes extensive use of station facilities, utilities, and H/W designs.

The ATF strawman provides a simple string redundancy with minimal cross strapping. This approach minimizes the complexity of the telescope while maintaining a single-fault-tolerant design. With the facility located on the manned SS, a strategy of replacing failed units instead of cross strapping is used to provide protection from multiple faults.

CONCLUSIONS
ATF STRAWMAN CONCEPT

SYSTEM REQUIREMENTS/CHARACTERISTICS

- OBSERVATIONS TO 10 PARSECS ARE REQUIRED TO OBTAIN AN ADEQUATE TARGET POPULATION.

- A SYSTEM ACCURACY OF 10 μARCSEC ALLOWS THE DETECTION OF PLANETS WITH MASSES OF 10 EARTHS AT 10 PARSECS.

- TO ACHIEVE THE NECESSARY VIEWING EFFICIENCY, THE STRAWMAN CONFIGURATION IS A f/13 SINGLE-MIRROR SYSTEM WITH AN APERATURE OF 1.25 m AND OVERALL DIMENSIONS OF 21.5 m LONG BY 1.85 m DIA.

- THE SS IS USED TO PROVIDE A STABLE LONG-TERM PLATFORM FOR THE ATF WITH SUBSTANTIAL BENEFITS DERIVED FROM THE POWER, COMMUNICATIONS, OPERATIONS, AND POINTING RESOURCES OF THE STATION.

- STRING REDUNDANCY PROVIDES FOR A RELATIVELY SIMPLE FAILURE TOLERANT SYSTEM.

11.3.2 Optical Subsystem. - To guard against nonmetric shifts in the "center" of star images, the ATF strawman is designed as a single mirror system with the mirror located at the pupil.

The unique optical elements used by the the telescope are the Ronchi ruling and the MAP, both of which are straightforward extrapolations of systems currently in operation at ground-based facilities. A Ronchi ruling is currently in use for astrometric measurements at the University of Pittsburgh's Allegheny Observatory, while the University of Arizona is currently operating a MAP at Steward Observatory for measurement of stellar and galactic radial velocities.

CONCLUSIONS
ATF STRAWMAN CONCEPT

OPTICAL SUBSYSTEM

- A SINGLE-ELEMENT, PUPILAR REFLECTOR MINIMZES POTENTIAL METRIC ERRORS.
- THE RONCHI RULING APPROACH IS IN USE AT THE UNIVERSITY OF PITTSBURGH'S ALLEGHENY OBSERVATORY WHILE A MAP IS OPERATING AT THE UNIVERSITY OF ARIZONA'S STEWARD OBSERVATORY.

11.3.3 Structures Subsystem. - The ATF strawman structural design is a monocoque graphite/epoxy tube divided into two pieces for packaging into the Space Shuttle bay. All components, both electrical and optical, are mounted to this basic structural element. An aluminum sunshade extends beyond the focal plane capped by a retractable aperture cover for protection from contamination and critical mispointing.

A vibration isolator is required between the telescope and its pointing mount to isolate the telescope from SS induced mechanical disturbances. This isolator is packaged separately from the telescope tube during launch, and is integrated on-orbit.

CONCLUSIONS
ATF STRAWMAN CONCEPT

STRUCTURES SUBSYSTEM

- SIMPLE MONOCOQUE STRUCTURE USING EXISTING MATERIALS PROVIDES ADEQUATE STABILITY
- SYMMETRICAL SUNSHADE ALLOWS A SUFFICIENT FIELD OF VIEW
- A RETRACTABLE APERTURE COVER PROTECTS THE TELESCOPE FROM CRITICAL MISPOINTING AND CONTAMINATION
- TELESCOPE SIZED AS A SINGLE STS PAYLOAD BUT REQUIRES A THREE-PIECE LAUNCH CONFIGURATION WITH ON-ORBIT ASSEMBLY

11.3.4 Thermal Control Subsystem. - The thermal design of the ATF strawman concept is such that no thermal fluids are required. This approach eliminates the mechanical disturbances which accompany circulating fluids, and does not require the passage of fluids across the pointing mount gimbal system. Instead, the ATF relies on passive radiators to reject heat generated by the electronics in the power-on condition, and replacement heaters to maintain minimum temperatures in the power-off condition.

A graphite/epoxy with a low coefficient of thermal expansion is used as the material for the telescope metering tube, minimizing the sensitivity to thermal excursions. This tube is then isolated from environmental extremes by thermal blankets, with electrical heat sources thermally isolated as well. To inhibit condensation on the primary mirror, the mirror is heated to a temperature above that of the surrounding structure.

CONCLUSIONS
ATF STRAWMAN CONCEPT

THERMAL CONTROL SUBSYSTEM

- ELECTRONICS TEMPERATURES CONTROLLED BY PASSIVE RADIATORS FOR POWER-ON, REPLACEMENT HEATERS FOR POWER-OFF CONDITIONS

- DESIGN PROVIDES REQUIRED STABILITY FOR MISSION THERMAL ENVIRONMENT
  - THERMAL BLANKETS USED TO ISOLATE THE TUBE FROM ENVIRONMENTAL EXTREMES
  - HEAT SOURCES (ELECTRONICS, ETC.) THERMALLY ISOLATED FROM THE TUBE
  - GRAPHITE/EPOXY TUBE MINIMIZES SENSITIVITY TO TEMPERATURE EXCURSIONS
  - PRIMARY MIRROR HEATED TO PREVENT CONDENSATION

11.3.5 Command and Data Subsystem. - The ATF strawman CDS design makes extensive use of SS-developed H/W and S/W, inheriting NIUs, SDPs, MDMs, and Operating System S/W from the station. The use of these SS designs ensures a straightforward interface with the station.

An ATF control console located in a pressurized module (also using predominantly SS-derived hardware/software) is provided to allow astronaut interface and control of the facility.

CONCLUSIONS
ATF STRAWMAN CONCEPT

COMMAND AND DATA SUBSYSTEM

- SUBSYSTEM MAKES EXTENSIVE USE OF SPACE STATION DEVELOPED H/W
- APPROACH ASSURES STRAIGHTFORWARD INTERFACE WITH STATION COMMAND AND DATA NETWORK
- CONTROL CONSOLE IN PRESSURIZED MODULE PROVIDES ASTRONAUT OPERATIONAL INTERFACE

11.3.6 Pointing and Control Subsystem. - The ATF strawman design assumes the use of a dedicated SS provided CPS for the full mission duration. This assumption allows the ATF to depend on the station for most of its pointing requirements, and uniquely provide only that supplemental pointing performance which is beyond the capabilities of a generic pointing system.

To provide this supplemental performance, the ATF strawman includes a Vibration Isolation/Vernier Pointing System operating on the principle of magnetic suspension. This system would provide the fine pointing capability required by the ATF as well as isolating the telescope from the SS dynamic disturbances.

To implement the required functions, the Pointing and Control Subsystem uses flight proven sun sensors and gyroscopes, in addition to star trackers and data processors which are being developed for other programs.

CONCLUSIONS
ATF STRAWMAN CONCEPT

POINTING AND CONTROL SUBSYSTEM

- ASSUMES THE DEDICATED USE OF A SS PROVIDED CPS
- FINE-POINTING AND VIBRATION ISOLATION TO BE PROVIDED BY THE ATF
- USES FLIGHT-PROVEN GYROS AND SUN SENSORS, AND STAR TRACKERS AND PROCESSORS DEVELOPED BY OTHER PROGRAMS

11.3.7 Power and Harness Subsystem. - Basic power for ATF operation will be supplied by the SS. Therefore, the requirements on the Power and Harness Subsystem are limited to regulation, unit ON/OFF power switching, current limiting, over/under-voltage control, and distribution.

The power electronics are expected to use power conversion boards inherited from designs developed by the SS Program, while the harness will use standard SS connector designed for EVA and/or robotic connect/disconnect.

CONCLUSIONS
ATF STRAWMAN CONCEPT

POWER AND HARNESS SUBSYSTEM

- POWER SUPPLIED BY THE SS
- POWER CONVERSION PROVIDED BY SS-DEVELOPED DESIGNS
- STANDARD SS CONNECTORS FOR EVA/ROBOTIC CONNECT/DISCONNECT

11.4 Interfaces

In the ATF strawman design, the attempt was made to minimize and simplify the external interfaces to the extent that this was practical.

The resulting interface requirements are for mechanical attach points, power, and communication (command and data). These three interfaces will be required for the telescope at both the CPS and the SS service bay, and for the ATF control console inside a pressurized module.

While in the shuttle, the ATF will require both a mechanical mounting interface and a simple electrical power interface for supplying heater power to maintain the system within its temperature limits.

CONCLUSIONS

INTERFACES

- MECHANICAL, POWER, AND DATA INTERFACES TO THE SS REQUIRED AT THE POINTING MOUNT AND SERVICE BAY.
- MECHANICAL, POWER, AND DATA INTERFACES TO THE SS REQUIRED IN A PRESSURIZED ENVIRONMENT FOR THE CONTROL CONSOLE.
- MECHANICAL AND HEATER POWER INTERFACES ONLY REQUIRED WITH THE SHUTTLE.

11.5 Mission Analysis

The mission analysis performed for this preliminary study concludes that the ATF, mounted on the SS, can adequately observe over the full celestial sphere with a relatively high viewing efficiency.

This high viewing efficiency can be obtained because a target set of approximately 100 stars virtually always provides that the telescope will have a target available for viewing. Excepting operational downtimes (for shuttle proximity operations, contamination events, station reboosts, etc) it is expected that a viewing efficiency of 80% can be achieved with a highly flexible viewing schedule.

The flexible viewing schedule also has the advantage that pointing constraints on the telescope (e.g., 90° velocity-vector avoidance angle) have minimal impact on the overall efficiency of the telescope.

CONCLUSIONS

MISSION ANALYSIS

- ALL PORTIONS OF THE SKY CAN BE VIEWED.
- WITH APPROXIMATELY 100 TARGETS, THE TELESCOPE WILL NEARLY ALWAYS HAVE A TARGET AVAILABLE FOR VIEWING.
- EXCEPTING OPERATIONAL DOWNTIME, A VIEWING EFFICIENCY APPROACHING 80% APPEARS ACHIEVABLE.
- POINTING CONSTRAINTS HAVE A MINIMAL EFFECT ON THE ATF VIEWING EFFICIENCY.

11.6 Mission Operations

The ATF strawman proposed in this study represents a facility with a single instrument and a single science-operating-mode.

Normal ATF operations will consist of repeated observations of the predetermined target set. The astrometric science requirements provide long windows for scheduling observations, thereby allowing simple and straightforward responses to anomalies. Typical anomaly responses consist of simply skipping an observation, or safing the facility and waiting for ground action, depending on the type of the anomaly.

Because of the relatively simple and repetitive nature of the measurements being made with the ATF, this study has been able to identify a straightforward operations approach comparable to that used for the ARC Pioneer spacecraft.

CONCLUSIONS

MISSION OPERATIONS

- THE SINGLE INSTRUMENT/SINGLE MODE NATURE OF THE ATF MINIMIZES THE REQUIREMENTS FOR COMPLEX COORDINATION OF TELESCOPE/SPACE STATION ACTIVITIES, AND GUEST INVESTIGATOR PLANNING AND SCHEDULING.

- REPETITIVE MEASUREMENTS OF SELECTED TARGETS OVER A LONG TIME SCALE ALLOW FOR FLEXIBLE OBSERVATION SCHEDULING AND RESCHEDULING, A RELAXED OBSERVATION PLANNING TIMELINE, AND A SIMPLE FAULT RESPONSE.

- STRAIGHTFORWARD OPERATIONS APPROACH IS COMPARABLE TO ARC PIONEER OR UNIVERSITY OF COLORADO SME OPERATIONS.

11.7 Testing

An ATF test philosophy has been identified which will provide confidence that the flight articles will operate successfully during flight via a series of functional, environmental, qualification and protoflight tests.

This test philosophy adopts a protoflight test approach wherein only one full flight vehicle will be assembled and tested. The telescope structure will be qualified using an engineering model, and spare electronics unit will be provided by use of qualification units.

A preliminary survey of test facilities was conducted, and it was established that adequate (although limited) facilities exist for testing the ATF.

CONCLUSIONS

TESTING

- A STANDARD PROTO-FLIGHT TEST APPROACH IS USED.
- ADEQUATE ENVIRONMENTAL TEST FACILITIES EXIST.

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16. Abstract

The Astrometric Telescope Facility Systems Definition Study Report documents the results of a 6-mon effort to define the basic goals and requirements of, and identify a strawman design for a spaceborne telescope facility capable of the detection and study of extrasolar planetary systems.

The study iterates the basic science rationale for Planetary Detection and describes an astrometric measurement technique using a Ronchi ruling to extract metric information. A strawman design, based on ground- and space-proven systems, is presented using the Space Station as the telescope platform.

Volume 2 provides a detailed technical description of the strawman facility and its requirements.

The study concludes that the detection of extrasolar planets is realizable through astrometry, using current technology in a long-life Earth-orbiting telescope.

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